Animated Representation of Uncertainty and Fuzziness in Spatial Planning Maps

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by

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Abstract

The Dutch Ministry of Housing, Spatial Planning and the Environment promotes the DURP initiative which aims at digital, exchangeable and comparable spatial plans. Many municipalities and provinces have already achieved digital plans for new spatial plans. However, the first experiences show that not all planning objects are comparable because some of them are uncertain and fuzzy. Among the users are spatial planners at different administrative levels who, in the plan preparation phase, are confronted with two problems of uncertainty and fuzziness. One problem is that planners are not able to correctly judge how some features that are continuous in reality influence options for possible future types of space use. This happens because these continuous features are discretely defined and conventionally represented by crisp boundaries on the map (e.g. a solid noise contour around a noise source at one noise level only). The second problem is created by incompletely defined planning objects which are currently represented by cartographic symbols in spatial planning maps. These planning objects, of which the location, boundaries, orientation, size and/or shape are not well defined, can therefore not be judged exactly. The presence of the problems above imposes research challenges on visualization of uncertainty and fuzziness in spatial planning maps.

This research concentrates on developing methods to effectively visualize uncertainty and fuzziness in animated representations by various combinations of graphic and dynamic visualization variables, and selecting or developing a method by which the usability of uncertainty and fuzziness displays in spatial planning maps can be evaluated. As a case study, provincial level spatial planning data of Noord-Brabant, the Netherlands were used. A conceptual framework for animated representation of uncertainty and fuzziness in spatial planning maps was proposed. Subsequently, the animated representations were designed and implemented in a prototype. For the usability study, the prototype was evaluated in a focus group session and a task and questionnaire session. The opinions and responses on the prototype provided by the focus group session were used to improve the prototype to minimize use problems in the later evaluation. Subsequently, the task and questionnaire session with the improved prototype was conducted to discover recognition of the uncertain and fuzzy aspects of spatial planning objects and to obtain usability scores for the animated representations. The results show that the spatial planners can be better aware of the uncertainty and fuzziness in spatial planning maps from such animated representations.

Key words: animation, uncertainty, fuzziness, graphic variables, dynamic visualization variables, spatial planning, usability evaluation

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Dedicated to my parents

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1. Introduction

1.1. Background and problem description

Spatial planning in the Netherlands is usually described as "the search for and the establishment of the best possible mutual adaptation of space and society for the benefit of society" (Brussaard, 1987). Spatial planning is a matter of policy by which the government gives conscious direction to spatial development and it also guides the process. Spatial planning in the Netherlands takes place within the administrative organization at three hierarchy levels i.e., national, provincial and municipal (Geertman & Toppen, 1990). The national level provides the long term global plan of the Netherlands. The provincial level provides a coherent policy and plan for a particular region. Detailed planning is done at municipal level where zoning plans are produced. A plan consists of planning objects; a planning object is "a policy object that is visualized on a map. It has a geographical location (dimension, shape, position) and descriptive characteristics (thematic attributes and policy measures and regulations)" (Vullings et al., 2007).

The Dutch Ministry of Housing, Spatial Planning and the Environment promoted the DURP initiative which is on digital exchange and dissemination of legal spatial planning data. It aims at digital, exchangeable and comparable spatial plans which enable to improve efficiency and effectiveness of evaluation and monitoring of spatial policy and to facilitate the communication between the government and civilians (Vullings et al., 2007). Therefore, there is a transition going on in which plans at all planning levels will be digitally stored and made available for users. Many municipalities and provinces have already achieved this for new spatial plans. The initial idea is that when plans are digitized and exchangeable, comparison of the digital spatial plans will not be a problem. However, the first experiences show that not all planning objects are comparable because some of them are uncertain or fuzzy. Among the users are spatial planners at different administrative levels who, in the plan preparation phase, are confronted with various types of uncertainty and fuzziness. Uncertainty and fuzziness limits the preparation and use of digital spatial plans if they are not dealt with in a right way. Therefore, it is necessary to deal with fuzzy and uncertain planning objects.

Uncertainty and fuzziness were hard to perceive in traditionally mapped data because they could not be expressed in an explicit way. To overcome these limitations, the GeO3 project "Omgaan met onzekere planobjecten bij monitoring en analyse van ruimtelijk beleid" (dealing with uncertain planning objects to facilitate monitoring and analysis of spatial policy) has been initiated in 2005 (see URL 1.1). The objective of GeO3 project is to study various properties of uncertainty in spatial planning objects, to define them and to suggest solutions to deal with them. The result will improve the transparency of spatial planning processes. The GeO3 project has already delivered a framework for dealing with the uncertainty in spatial planning (Vullings et al., 2007). Improved visualization is one of the solutions that is suggested to deal with the uncertainty and fuzziness.

The problems of uncertainty and fuzziness which the improved visualization can deal with occur mostly in the plan preparation phase at lower than national levels, particularly at municipal level. One problem is that planners are not able to correctly judge how some planning objects that are continuous in reality influence options for possible future types of space (or land) use. This happens because these continuous features are conventionally represented by crisp boundaries on the map (e.g. a solid noise contour around a noise source at one noise level only). A special case is uncertainty created by scale (or scale ranges). Symbols and boundaries used to indicate desired developments or directives on small scale maps at higher levels have to be integrated in more detailed, larger scale (zoning) maps. The integration of different scale planning objects causes fuzziness of the boundaries or symbols descriptions, and sometimes the planning target locations cannot be pinpointed exactly. The second problem is created by incompletely defined cartographic symbols in spatial planning maps. Therefore these planning objects, of which the location, boundaries, orientation, size and/or shape are not well defined, can not be judged exactly. A typical example is a zone or arrow symbol to indicate in which direction an ecological transition zone should be extended. The exact location, shape, size and sometimes direction of planning objects that are, or have to be, represented in the map is uncertain. Therefore, some spatial planning decisions which are made by spatial planners are based on uncertain information. The presence of the problems above imposes research challenges on visualization of uncertainty and fuzziness in spatial planning maps. Leitner and Buttenfield (2000) suggested that cartographic representation of data uncertainty is helpful to decision makers. Visualization of uncertainty and fuzziness is a crucial issue in the plan preparation phase, since planners will be better aware and informed about the uncertainties, and are then able to better evaluate which options are available for future space (land) use. By providing information about data uncertainty and fuzziness in an explicit visual way, spatial planners will be assisted with making better and more correct decisions.

The basic method of visually representing uncertainty and fuzziness is based on the direct application of Bertin's (1983) graphic variables and their extensions (MacEachren, 1992). The original set of variables includes location, size, (colour) value, grain (texture), colour (hue), orientation and shape. Still, other variables have been suggested as an addition to the original variables of Bertin, for example: colour saturation, crispness, transparency, resolution (MacEachren, 1992). Another way to affect the effectiveness of uncertainty and fuzziness representation is by applying dynamic visualization variables. These have been originally elaborated by Dibiase et al. (1992) and MacEachren (1994a) and are supposed to be: display date (or moment of display), duration, frequency, sequence (or order), rate of change and synchronization. Blok (2005) concluded that display date (or moment of display), duration, sequence (or order) and frequency are the only four dynamic visualization variables and that rate of change and synchronization can better be seen as effects (e.g. of interactions with other dynamic variables). In this research, graphic variables and dynamic visualization variables issues should be related to the representation of uncertainty and fuzziness.

In this research, the emphasis will be on cartographic animation as a visualization method instead of on static methods, because the later have already been investigated by many researchers (see Chapter3.4). Compared to static methods, cartographic animation provides additional options that have not been fully investigated yet; it offers the viewer an extensive look by changing representation. The change can be due to visual representation variable manipulations i.e. applying various combinations of graphic and dynamic visualization variables. In cartographic animation data are represented by graphic variables in the spatial dimensions of the maps. In addition, dynamic visualization variables are applied in the temporal dimensions (display time) of a running animation. The combination of graphic and dynamic visualization variables can provide some animated cartographic symbols, e.g. moving or blinking symbols, that may be useful to represent uncertainty and fuzziness. However, problems may arise because the user may become annoyed by these effects and, therefore, ways to avoid the annoying effects need to be addressed as well.

Although many methods for displaying uncertainty and fuzziness on maps have been developed (see MacEachren, 1995) few have been formally tested with users. The need for empirical testing can be argued for two reasons. The first reason is to better represent uncertainty and fuzziness based on better understanding of how people work with them. Secondly, results from testing can help to develop a conceptual framework and guidelines for representing uncertainty and fuzziness (Leitner & Buttenfield, 2000).

More research is required to investigate and gain an understanding of the animated representations of uncertainty and fuzziness. For example, animated representations as suggested by Shepard (1994) seem potentially useful, but have, as far as known, not been empirically evaluated yet. The extent to which different representation methods support tasks will be investigated. The investigation will focus on the display of uncertainty and fuzziness as well as on testing and evaluating the usability of the animated representations of spatial plans in the Netherlands.

1.2. Research objectives

The main research objectives of this study are:

- To develop methods to effectively visualize uncertainty and fuzziness in animated representations by various combinations of graphic and dynamic visualization variables.
- To select or develop a method by which the usability of uncertainty and fuzziness display in spatial planning maps can be evaluated.

1.3. Research questions

The main questions are:

1. Which planning objects are uncertain and fuzzy in spatial planning maps?
2. What characteristics of the uncertain and fuzzy planning objects play a role in the plan preparation phase of spatial planning?
3. How can these planning objects be represented in an (interactive) animated way by combinations of graphic and dynamic visualization variables?
4. How can the annoyance of users by some animated effects, e.g. moving or blinking objects, be eliminated?

5. How to select or develop a method for testing and evaluating whether the proposed application works?
6. Which combinations of variables can be recommended to aid spatial planners in making better decisions, based on user tests?

1.4. Method adopted

The main aspects of the research method, which consist of four phases, are outlined below (see Figure 1.1).

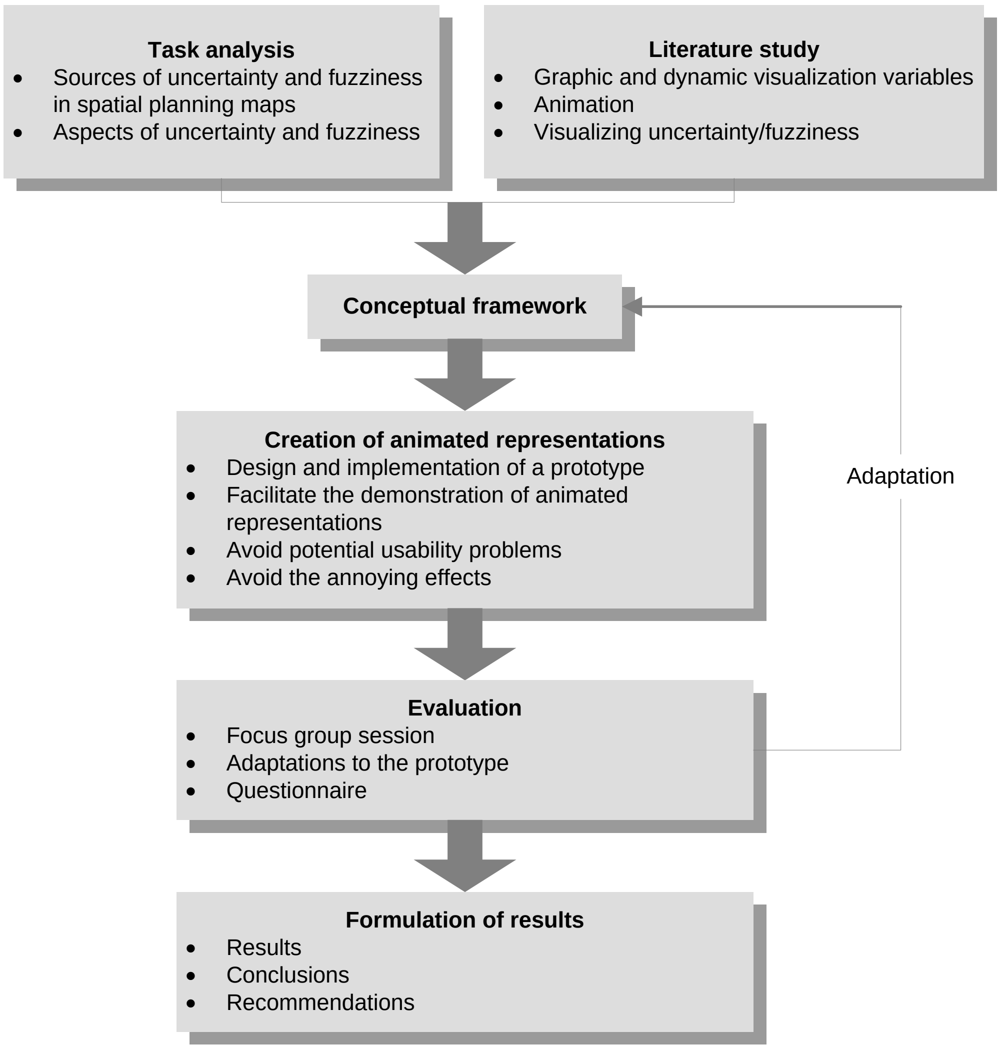


Figure 1.1 Main research phases

1. *Task analysis and development of a conceptual framework*

The sources of uncertainty and fuzziness in spatial planning maps are investigated. In addition, the aspects of fuzzy and uncertain characteristics of planning objects are identified. In this phase, answers are provided to the first research question: *Which planning objects are fuzzy and uncertain in spatial planning maps?*, and the second research question, i.e. *What characteristics of the fuzzy and uncertain planning objects play a role in the plan preparation phase of spatial planning?* The characteristics of graphic and dynamic visualization variables are investigated in this phase also. Potential effectiveness of using the various combinations of graphic and dynamic visualization variables for animated representations of uncertainty and fuzziness are investigated too. The main approach in this phase is literature study. The results are presented as a conceptual framework for representing uncertainty and fuzziness. The third research question, i.e. *How can these planning objects be represented in an (interactive) animated way by combinations of graphic and dynamic visualization variables?*, are dealt with in the last part of this phase.

2. *Creation of animated representations*

As a case study, provincial level spatial planning data of Noord-Brabant, the Netherlands are used. The alternative representations of uncertainty and fuzziness based on the conceptual framework of the first phase are designed and implemented in animations using Macromedia Flash 8. A way that tries to facilitate the demonstration of the animated representations of different planning objects and avoid the potential usability problems is addressed. In order to answer the fourth research question *(How can the annoyance of users by some animated effects, e.g. moving or blinking objects, be eliminated?)*, a way that tries to avoid the annoying effects is also addressed in this phase.

3. *Evaluation*

The animated representations created in the second phase are evaluated in this phase. A focus group and a questionnaire method are selected as evaluation methods. A focus group session with a small number of domain experts is organized. The results on the prototype from the focus group session are used to improve the prototype and to minimize usability problems in the later usability testing. Subsequently, a task and questionnaire session of the improved prototype is conducted to discover the usability scores of animated representations of uncertainty and fuzziness in terms of effectiveness, efficiency and user satisfaction. The fifth research question: *How to select or develop a method for testing and evaluating whether the proposed application works?*, is answered in this phase.

4. *Formulation of the result*

The data collected during the evaluation sessions are used for analysis. Results and conclusions are drawn from this. The results will show the usability scores of the animated representations of uncertainty and fuzziness. Conclusions are formulated by providing the answers to the research questions. Recommendations for the representation of uncertainty and fuzziness in Dutch spatial planning maps will be formulated. This is used to answer the last research question *(Which combinations of variables can be recommended to aid spatial planners in making better decisions, based on user tests?)*. Finally suggestions for further research are given.

1.5. Organization of the thesis

The remaining part of the thesis is organized in six chapters as below:

Chapter 2 describes terminology to avoid confusion. It discusses the definitions of uncertainty and fuzziness. It also provides the meaning of uncertainty and fuzziness in Dutch spatial planning maps. The sources and aspects of uncertainty and fuzziness in Dutch spatial planning maps are distinguished.

Chapter 3 deals with the visualization of uncertainty and fuzziness. It describes the reason to choose animated representations as a visualization method in this research. Then, it illustrates the possibilities to use graphic and dynamic visualization variables. This is followed by a section of methods used to visually represent uncertainty and fuzziness. Examples of evaluation are also discussed in this chapter.

Chapter 4 conceptually defines animated cartographic symbols. Then, it proposes a conceptual framework which constitutes a general formalization within which the animated cartographic symbols can be designed using the graphic and dynamic visualization variables according to the aspects of uncertainty and fuzziness in spatial planning maps.

Chapter 5 describes the implementation of a prototype application which was designed to fulfil the conceptual framework presented in Chapter 4. It provides alternative animated representations, with a focus on the case study data. The overall design is based on data characteristics and convenience of users' requirement for the evaluation of the prototype. The prototype supports to display some animated cartographic symbols to represent the uncertain/fuzzy planning objects.

Chapter 6 describes the evaluation methods applied and the results from evaluation. It begins with a description of the usability concept. This is followed by a brief introduction of evaluation methods and a selection for this research. Details of the procedures of focus group sessions and questionnaire sessions will follow. The results of the analysis are also summarized.

Chapter 7 outlines the main conclusion, and the recommendations for further research.

2. Uncertainty and fuzziness

The terms uncertainty and fuzziness are often confused. The aim of this chapter is to remove possible confusion about intermixed terminology by defining the concepts in the context of Dutch spatial planning maps.

2.1. Uncertainty

In the literature today, there is no consensus on the definition of uncertainty or on a universal method to represent it (Pang, 2001). Conceptualizing geographical information uncertainty therefore presents a considerable challenge in GIScience research. Buttenfield (1993) considered ambiguous terminology involved in conceptualizing uncertainty as one of the impediments in effectively representing uncertainty. This section briefly defines the uncertainty.

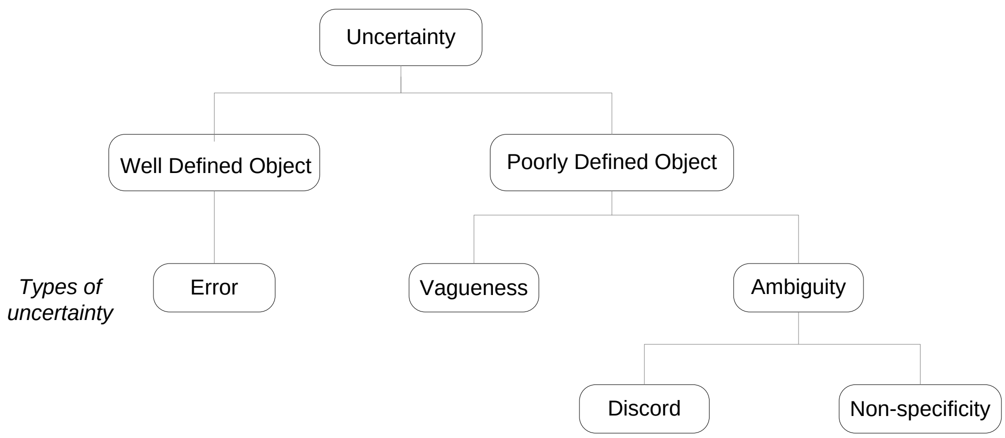


Figure 2.1 A conceptual model of uncertainty in spatial data (Source: Fisher et al., 2006)

Based on proposals by Fisher (1999), Fisher et al. (2006), Zhang and Goodchild (2002) and Leyk et al. (2005), uncertainty is distinguished as well defined and poorly defined objects and it can be further classified into three types, i.e. error, vagueness and ambiguity, they all contain a degree of indetermination (see Figure 2.1). Therefore uncertainty forms an umbrella term for these concepts. *Error* as one aspect of the uncertainty, presents the deviation between a given value and its true value (Worboys, 1998). In the GIS community, error is considered as a concept of uncertainty to describe the measurable deviation from the true state where no problems of vague or ambiguous definition occur as proposed by some authors (e.g. Fisher, 1999; Zhang & Goodchild, 2002). *Vagueness* can be defined as "indeterminacy due to lack of distinctness between ill-defined or fuzzy classes of objects or individual objects" (Leyk et al., 2005). It represents imprecision in concepts and definitions used to describe the information. Vagueness can be due to the inherent nature of the object, or the result of the method of observation or of the purpose and requirements of the user (Worboys, 1998). *Ambiguity* is the confusion among concepts which have the same name, but more than one definition (Fisher, 2000; Leyk et al., 2005). Two types of ambiguity have been distinguished as *discord* and *non-specificity.* Discord is defined as the lack of agreement that occurs under different classification schemes or interpretations. Non-specificity describes the occurrence of ambiguity if the assignment of an object to a class is unsettled at all (Fisher, 1999; Leyk et al., 2005). To summarize, there is a distinction between error, vagueness and ambiguity. Error is not caused by the problem of vague or ambiguous definition. Vagueness occurs due to the indeterminately or poorly defined terms and definitions, such as overlapping or incomplete definitions. It may cause problems in thematic, locational and temporal aspects. Ambiguity is due to definitions with a different meaning, such as the confusion of definitions in classification systems. Ambiguity does not consider the environment of the data (Leyk et al., 2005).

In this thesis, the definition of uncertainty given by the GeO3 project is used: uncertainty is "the acknowledgement that one does not know the situation of a system exactly because of imperfect or incomplete information" (Vullings et al., 2007). The spatial planners are uncertain about the real situation of planning objects in spatial planning maps due to imperfect visual representations; they are unable to deal with it properly. Therefore, uncertainty has a direct influence on the effective implementation of spatial plans.

2.2. Fuzziness

Vagueness can be considered equivalent to fuzziness, a concept that is often used in literature. Fuzziness is "a type of imprecision in characterizing classes that for various reasons cannot have, or do not have sharply defined boundaries. These inexactly defined classes are called fuzzy sets" (Burrough, 1996). In reality, some concepts should be considered as fuzzy objects such as mountains, rivers and forest, because they are not crisp objects at all. Since Zadeh (1965) introduced the idea of fuzzy sets dealing with the fuzzy concepts in a definable way, it is appropriate to use fuzzy sets when we have to deal with fuzziness in mathematical or conceptual methods of natural features.

A spatial object in GIS is usually considered to have a spatial, non-spatial (or attribute) and temporal component. Fuzziness may exist in all of these aspects. Tang (2004) distinguished four types of fuzziness of spatial objects i.e. fuzziness in object class, fuzziness in object attributes, fuzziness in location and fuzziness in time. Fuzziness in object class is usually caused by vague category definitions. For example, in the Oxford English Dictionary forest is explained as "an extensive tract of land covered with trees and undergrowth, sometimes intermingled with pasture" (see URL 2.1), in which the term "extensive" is not clear to decide how much degree of extent is extensive. Fuzziness in object attributes is also caused by the vagueness existing in object attributes description, if we consider the attributes as a class of attribute, the fuzziness in object attributes can be regarded as the fuzziness in object class. Locational fuzziness includes two parts: (1) the precise location of geographic objects is known, including the boundaries and transition zones between them, but it is uncertain how to classify or precisely represent them. This kind of fuzziness can be considered as class fuzziness; (2) the category definition imprecisely represents the spatial component, so it is impossible to classify them crisply. Temporal fuzziness manifests when we have incomplete or inexact temporal information, such as incomplete temporal record of when something happens (Tang, 2004).

2.3. Uncertainty and fuzziness in Dutch spatial planning maps

The preceding sections have discussed the definitions related to uncertainty and fuzziness. This section deals in more detail with some aspects of uncertainty and fuzziness in Dutch spatial planning maps. Fuzziness (as explained before) is usually an inherent property of the geographic phenomenon itself. It means that the considered object or phenomenon cannot be precisely represented, such as a noise boundary and a coastline. Uncertainty corresponds to a lack of knowledge about an object, a fact that is usually caused by limitations of the observation.

The GeO3 project has already delivered a framework for dealing with the uncertainty in spatial planning. In this framework, the taxonomy of uncertainty of Fisher et al. is extended to fit the Dutch spatial planning domain (see Figure 2.2) (Vullings et al., 2007). IN the uncertainty taxonomy in spatial planning proposed by GeO3Nature, sources of uncertainty and possible solutions are distinguished and visualized in the hierarchical division of the uncertainty taxonomy.

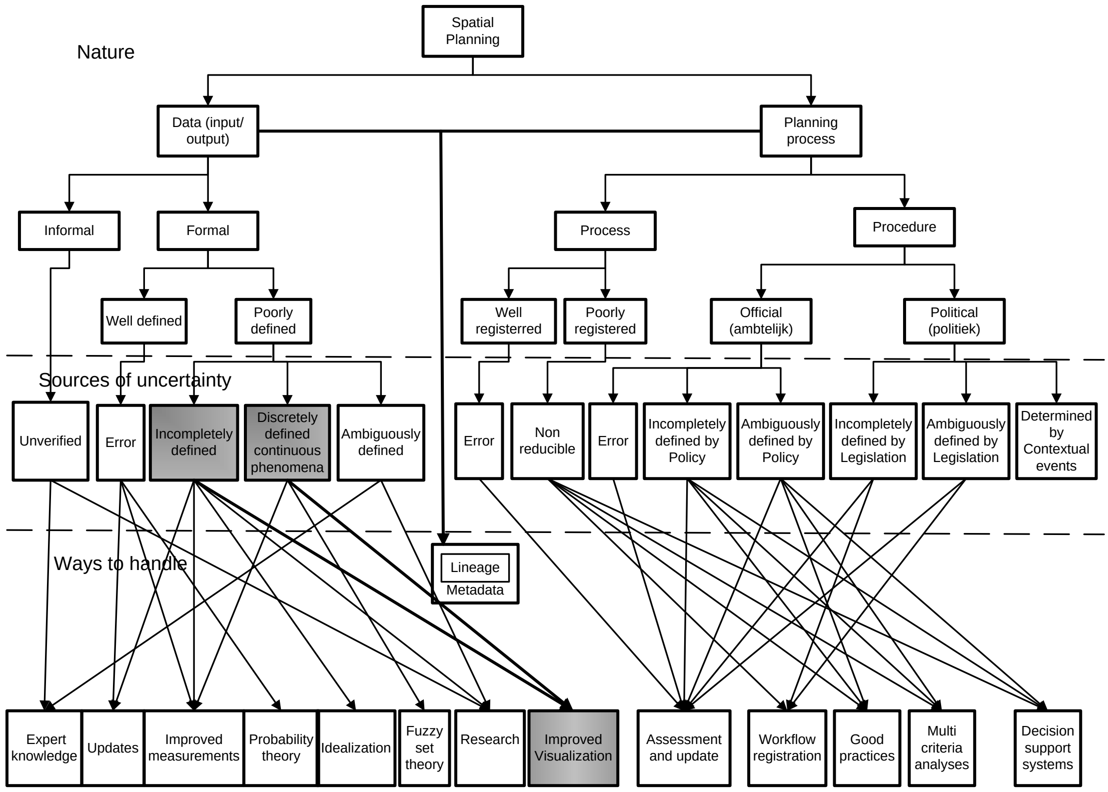


Figure 2.2 A taxonomy of uncertainty in spatial planning (source: Vullings et al., 2007)

2.3.1. Sources of uncertainty and fuzziness in spatial planning maps

GeO3 suggests different solutions to deal with uncertainty based on different sources. Among the solutions, “improved visualization”, which is the focus of this thesis, was suggested to deal with incompletely defined planning objects (e.g. uncertainty caused by cartographic symbols, see below) and discretely defined continuous phenomena (i.e. fuzzy objects).

1. Incompletely defined planning objects.

These are planning objects of which the location, boundaries, orientation, size and/or shape are not well defined in the DLM (Digital Landscape Model), and that are currently represented by cartographic symbols (point, line and area symbols) that do not indicate what the (level of) uncertainty is. The spatial planners are confronted with the uncertainty to pin-point them in reality.

Point symbols in existing spatial planning maps have many types such as solid stars, open stars letter symbols etc. In Figure 2.3, open red stars represent a business area; solid red and blue stars show tourist sites and concentrations of aquatic recreation respectively; the letter symbols W and M mean public water and military terrain respectively. Currently, point symbols are used to indicate the location of different planning objects by means of different shapes and colours. However, when spatial planners deal with them, the exact location and the size of these objects are uncertain because the information is not precisely known or supposed to be determined later.

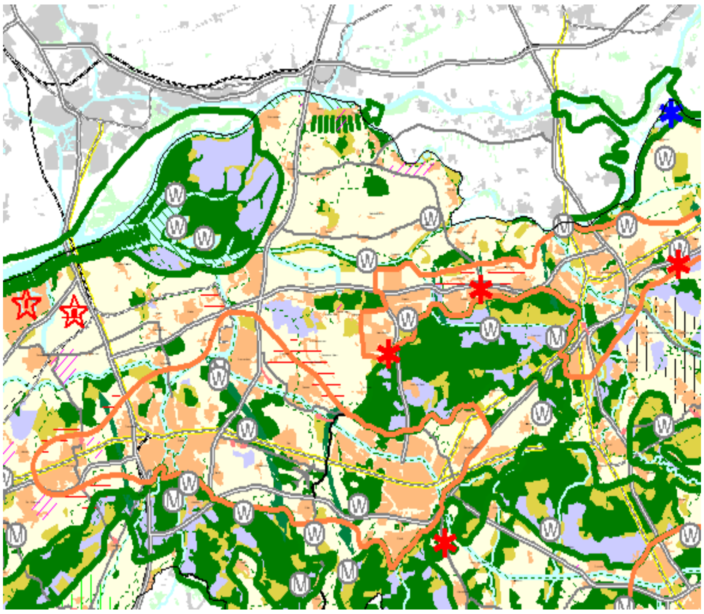


Figure 2.3 Example of point symbols in spatial planning maps (source: Noord-Brabant, 2002)

Among line symbols, the most representative example is the arrow symbol. In Figure 2.4, the green arrows show the direction of extension of landscape ecological zones, the pink arrows represent access roads to the open area. The spatial planners do not know how precise the orientation and location of arrows is and what the exact shape and size of these planning objects are.

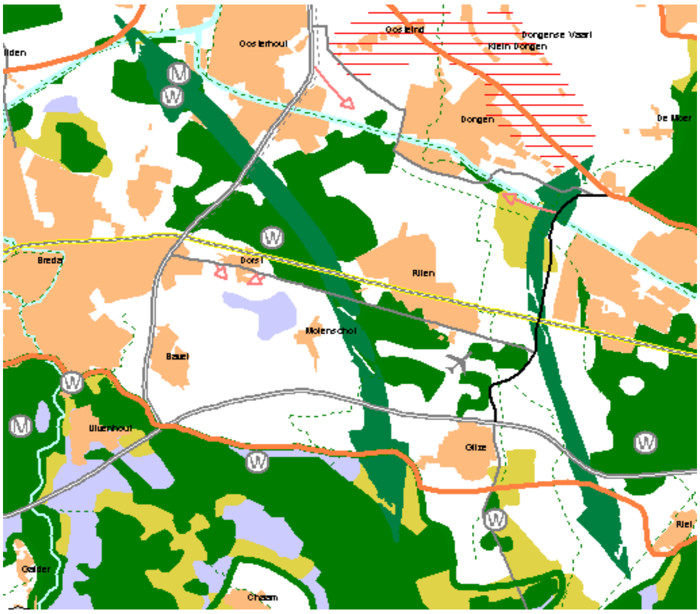


Figure 2.4 Example of line symbols in spatial planning maps (source: Noord-Brabant, 2002)

Area symbols include hatching, squares and rectangular symbols etc. Figure 2.5 shows an example of hatching in spatial planning maps. The black vertical hatching means search area cattle concentrations; the purple diagonal hatching reflects possible extension of greenhouse farming. Examples of squares and rectangles are shown in Figure 2.6: the black rectangles show strategic development areas; the red and purple rectangles are residential and business areas to be developed respectively. The different colours, thickness and/or orientation of these symbols express different planning objects, while the size of the symbols corresponds to the size of the planning area. But the exact location, shape and sometimes directions cannot be judged exactly since it is not known.

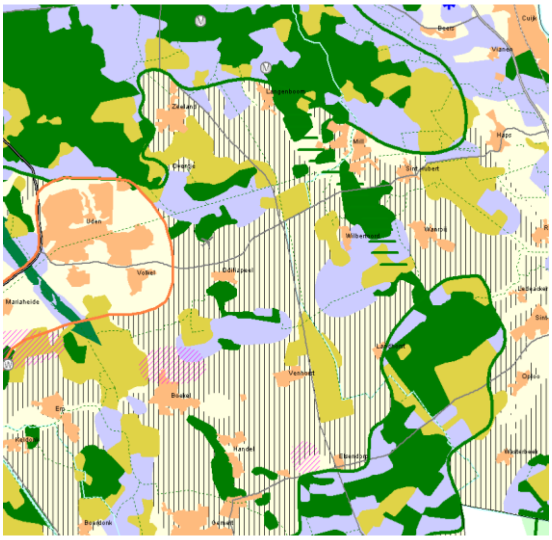


Figure 2.5 Examples of hatching (area symbols) in spatial planning maps (source: Noord-Brabant, 2002)

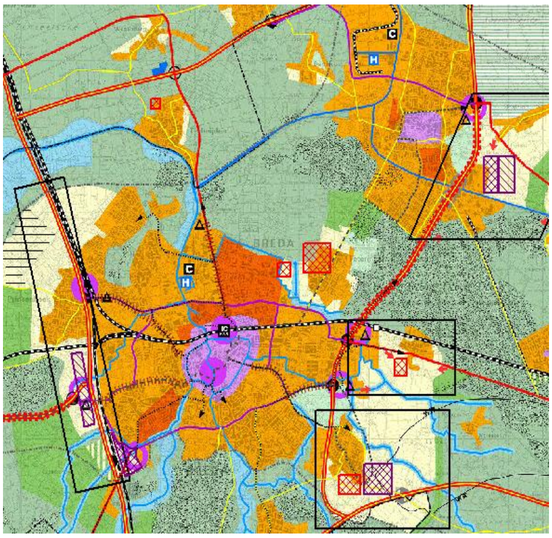


Figure 2.6 Examples of squares and rectangles (area symbols) in spatial planning maps. (source: Noord-Brabant, 2002)

2. Discretely defined continuous phenomena (fuzzy objects)

These planning objects deal with discretely defined continuous phenomena (i.e. fuzzy objects) such as noise pollution, odour circles, etc. The information of the planning objects is detailed and well defined but the exact location of boundaries is fuzzy (vague). The problem is the incorrect visual representation in spatial planning maps. Planning objects in spatial planning maps are understood as discrete objects because of their crisp boundaries. But what they express, or what we perceive when we look at them in reality, is continuous. Fuzziness in this case intrinsically belongs to the nature of the object. For example, noise in reality consecutively decreases away from the noise source. The wind and other natural factors influence how the noise spreads around the source. But noise in spatial planning maps is usually expressed by a solid and crisp noise contour around a noise source at one noise level only (see Figure 2.7). Therefore, the planners are not able to understand their real impact. The expectation of "improved visualization" in this case is a better representation than the crisp and solid way currently applied in the spatial planning maps.

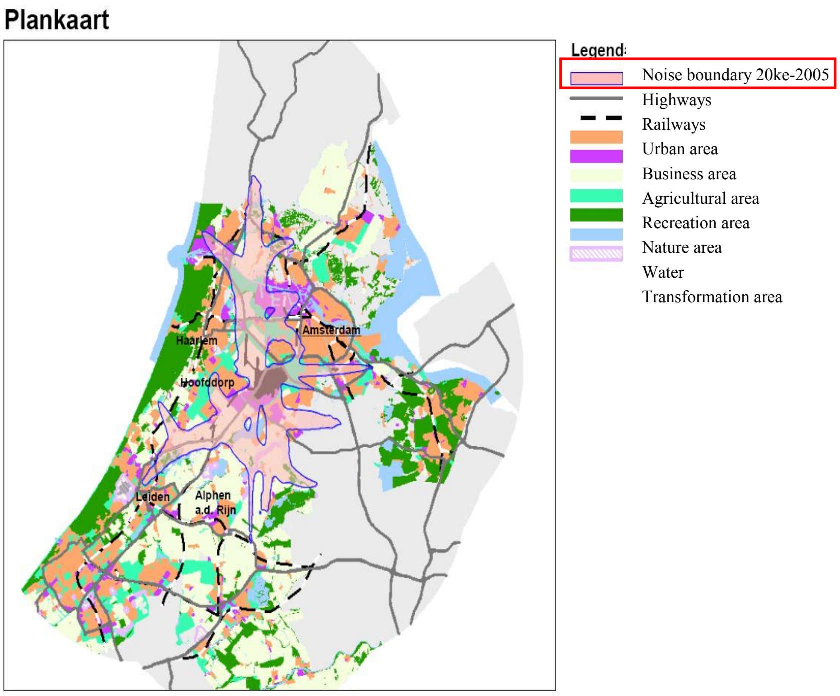


Figure 2.7 Example of noise boundary of Schiphol Airport in Amsterdam. The red rectangle shows the noise boundary in the legend (source: GeO3-project, 2007)

One special case of this source of uncertainty is uncertainty due to scale, related to integration or implementation of planning objects at different levels. For example, national spatial plans only give national indications of desired future space (or land) use on small scale maps, while municipal or provincial plans (zoning plans) must be more detailed and precise on larger scale maps (related to different reference datasets used for digitizing). Yet, national directives have to be taken into account (see Figure 2.8). The boundaries or cartographic symbol descriptions of these developments or directives are uncertain to the spatial planners. Therefore the scale (or scale ranges) will most likely influence the solutions that are proposed.

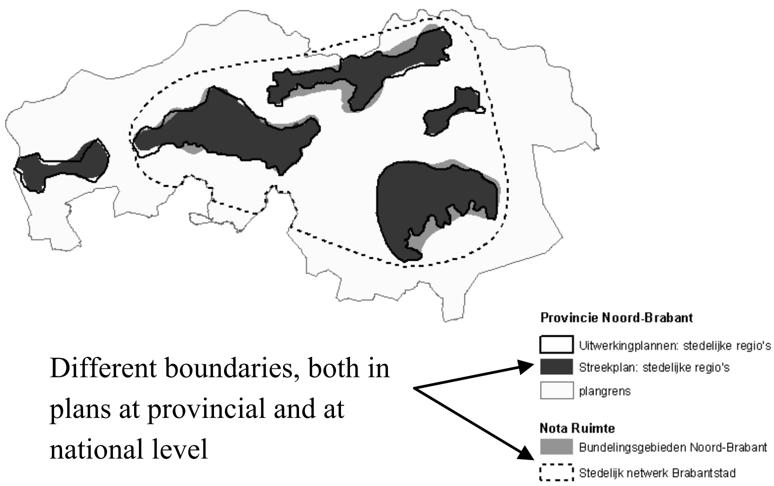


Figure 2.8 Example of a problem due to the integration of planning objects at different scales (source: GeO3-project, 2007)

2.3.2. Uncertainty and fuzziness aspects in spatial planning maps

For the two sources of uncertainty and fuzziness in spatial planning maps (which are incompletely defined planning objects and discretely defined continuous phenomena, i.e. fuzzy objects), five uncertainty and fuzziness aspects can be distinguished in the geometric domain (see Figure 2.9). These are *location*, *boundary*, *orientation*, *size* and *shape* Uncertainty and fuzziness exists in these five aspects.

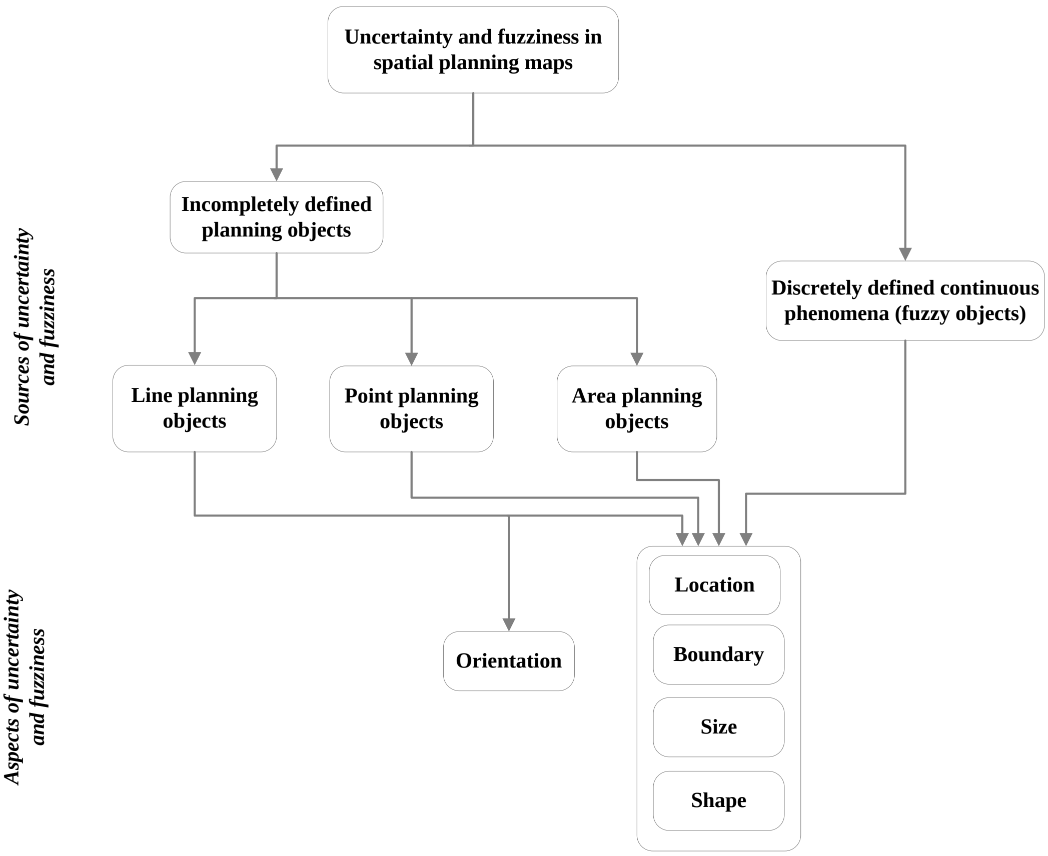


Figure 2.9 A taxonomy of uncertainty and fuzziness in spatial planning maps in the context of this research

The five geometrical aspects of uncertainty and fuzziness are all involved in line planning objects. It means that spatial planners need to deal with these uncertainty and fuzziness aspects when they prepare spatial planning decisions for line planning objects. Orientation as an aspect of uncertainty and fuzziness is not concerned in point, area and fuzzy planning objects because orientation does not have influence on them when spatial planners prepare planning decisions.

Currently, these aspects of uncertainty and fuzziness are not represented in spatial planning maps. An improved visualization is necessary to make planners aware of these fuzzy or incompletely defined planning objects, represented by cartographic symbols.

2.4. Summary

This chapter has dealt with the definitions of uncertainty and fuzziness. Two sources and five geometrical aspects of uncertainty and fuzziness in Dutch spatial planning maps are distinguished. The discussion of these terms and definitions removes possible confusion about intermixed terminology. Uncertainty and fuzziness in spatial planning maps occur to a rather high degree. Awareness of, and information about indeterminacies contained in the maps can be improved by a better visual representation in the DCM (Digital Cartography Model). With poor visual representation or design choices, uncertainty visualization could lead to more uncertainty about the data depicted (MacEachren et al., 2005). Uncertainty and fuzziness affect the process and outcomes of planning decisions. Therefore, efforts to develop better visualization methods and tools can help spatial planners to understand and better deal with uncertainty and fuzziness.

3. Visualization of uncertainty and fuzziness

3.1. Introduction

The two sources of uncertainty and fuzziness in Dutch spatial planning maps which are addressed in chapter 2 impose research challenges on visualization of them. The focus of this research is on animated methods and technologies to visualizing uncertainty and fuzziness in spatial planning maps. This chapter discusses existing and documented techniques to establish a number of methods that could be successful in representing uncertainty or fuzziness. It begins with a discussion of the visual representation variables (Section 3.2). Firstly, it describes the graphic variables and their modifications and extensions (Subsection 3.2.1). Secondly, it distinguishes the definition and the relationships of dynamic visualization variables (Subsection 3.2.2). Section 3.3 discusses the basic concepts and types of animated maps. It is followed by the reason to focus on cartographic animation in this study. Section 3.4 describes methods for visualizing uncertainty. This discussion is divided into three Subsections. First, the fundamental aspects of visual representation are described (Subsection 3.4.1). Secondly, several approaches to represent uncertainty by using different additional graphical objects are addressed (Subsection 3.4.2). Thirdly, dynamic representations of uncertainty are described (Subsection 3.4.3). Section 3.5 focuses on several studies which have addressed empirical evaluation of the effectiveness of specific uncertainty visualization methods.

3.2. Visual representation variables

3.2.1. Graphic variables

Graphic variables are visible within the two or three spatial dimensions used to represent geographic data. Bertin (1983) appears to be the first cartographic author to formally propose a set of fundamental graphic variables which include location, size, value, grain (texture), colour (hue), orientation and shape. These variables except location will be called graphic variables in this thesis (as shown in Figure 3.1). For each graphic variable, Bertin also proposed rules for their appropriate use, based on measurement levels of the data (see below).

After Bertin's original set of graphic variables, a range of modifications and extensions was subsequently offered by several authors. Morrison (1974, cite from MacEachren, 1995) added *arrangement* and *colour saturation* to Bertin's list. The concept of arrangement involves two components i.e. dispersion and spacing (Muehrcke & Muehrcke, 1992). Colour saturation was given to describe the relative purity of colour by adding different proportions of grey, which is the third dimension of colour. Bertin mentioned colour saturation, but he merged it with colour hue. Currently, most graphic design software enables individual control of the three dimensions of colour i.e. hue, value (or lightness) and saturation. Therefore, it is better to separate colour saturation from hue. In 1990, Caivano (cite from MacEachren, 1995) modified *texture* as a tripartite variable: he proposed three dimensions of texture i.e. directionality (the ratio of length to width of texture units), size (of the texture units) and density (ratio of texture units to the background). He also pointed out that these texture dimensions can be operated individually or together, resulting in a three dimensional texture space as shown in Figure 3.2.

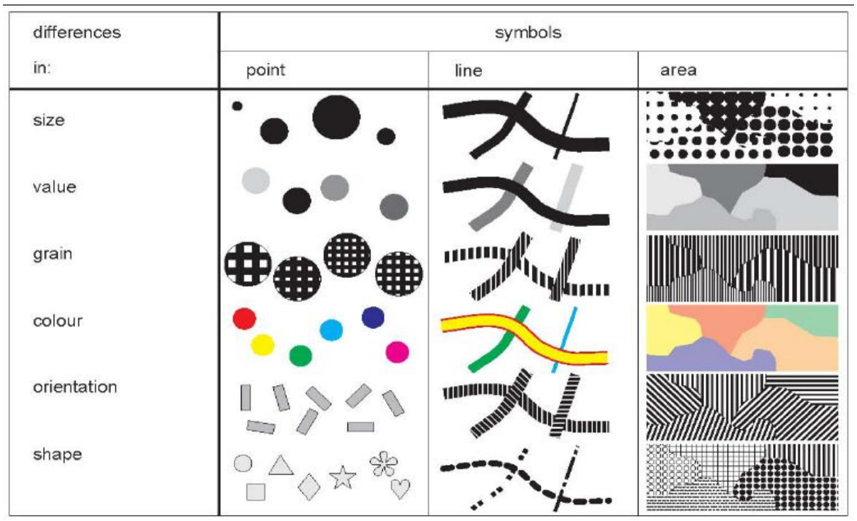


Figure 3.1 Basic graphic variables (Source: Kraak & Ormeling, 2003)

MacEachren (1992) proposed an extended visual variable *focus* to depict uncertainty. He distinguished four types of focus: edge and fill crispness both of which are dealing with sharpness of detail; the third type is resolution of base information, and the last type is transparency of an intervening layer (called "fog"). In 1995, MacEachren proposed *clarity* as an alternative term of focus, three visual variables which are crispness, transparency and resolution are subdivisions of clarity. Crispness can adjust the visible detail of a map by means of selective spatial filtering of edges, fill, or both. Resolution deals with spatial precision change. Transparency uses a "fog" to obscure the map theme when dealing with uncertainty in the representation (MacEachren, 1995).

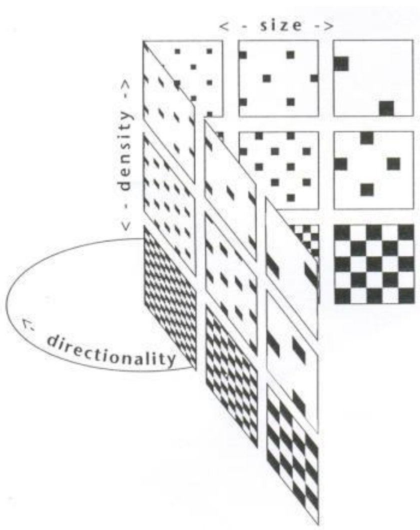


Figure 3.2 Three-dimensional texture space (Source: MacEachren, 1995)

Adaptations to the syntactics are also proposed by some authors. Bertin categorized each visual variable in terms of whether or not it is appropriate for depicting quantitative information, ordered information, or nominal information. Morrison's 9 graphic variables were considered suitable for two categories i.e. nominal or ordinal/interval/ratio (cite from MacEachren, 1995). MacEachren proposed visual variable syntactics in which 12 variables were matched to numerical, ordinal and nominal information with 3 degrees of appropriateness. These syntactics assist to evaluate the suitability of each graphic variable in relation to phenomena (MacEachren, 1995).

3.2.2. Dynamic visualization variables

Bertin (1983) stated that "movements introduce only one additional variable", MacEachren (1995) concluded that this statement is not correct. In cartographic animations a temporal dimension (i.e. display time) can be added. With display time a number of variables can be applied to control the animation. To this end , "new" visual variables have been introduced by DiBiase et al. (1992) and MacEachren (1994a). These will be called the *dynamic visualization variables* from here on. Dynamic visualization variables are used for animated representations. DiBiase et al. (1992) elaborated the dynamic variables *order*, *duration* and *rate of change*. A few years later, MacEachren (1994a) added *moment of display*, *frequency* and *synchronization*. For each dynamic visualization variable, they also proposed suggestions for their use. Blok (2005) concluded that *moment of display (or display date)*, *order*, *duration* and *frequency* are the only four dynamic visualization variables and that rate of change and synchronization can better be seen as *effects* of changes (e.g. of interactions with other dynamic visualization variables). She also provided the definition of these four dynamic visualization variables which were chosen to be used in this research as shown in Table 3.1.

Table 3.1 Definition of dynamic visualization variables for use in animations (Blok, 2005)

Dynamic visualization variables	*Definition*
Moment of display	Position of a state or a change in the representation in display time.
Order	Structured sequence of states or changes in the representation in display time. Order is structured because it is based on a chosen principle or criterion (e.g. chronological or based on particular attribute values).
Duration	Length in display time of a state or change in the representation.
Frequency	Repetition or number of identical states or changes in the representation per unit of display time.

The dynamic visualization variables listed in Table 3.1 are not independent of each other, there are relationships between them as shown in Figure 3.3. Moment of display is the basic variable where moments marked by the initiation of a change or a new state form the basis for perception of all other dynamic visualization variables. Duration (the distance between at least two marked moments of display) and order can be considered as primary derived variables, because they need two or more moments of display. Frequency is a function of order and duration; all variables above are involved to present frequency. Hence, frequency is a secondary derived variable (Blok, 2005).

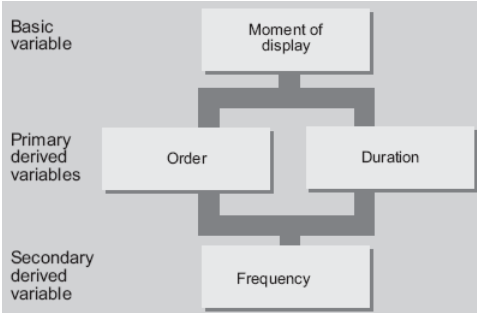


Figure 3.3 Relationships between the dynamic visualization variables (Source: Blok, 2005)

The dynamic visualization variables can only be observed in the temporal dimension (display time) of a running animation. They enrich the graphics with dynamism in the temporal dimension (Blok, 2005). The dynamic visualization variables can be used to represent information in both temporal animations and non-temporal animations. Therefore, dynamic visualization variables can be related to the (temporal or non-temporal) animated representation of uncertainty and fuzziness.

3.3. Animated map

The animated map, also called cartographic animation, has become an important tool in recent years. Cartographic animations can represent the dynamic characteristics of geodata in an animated map or show spatial information dynamically in a sequence of static maps. Cartographic animations can be subdivided into temporal and non-temporal animations. In temporal animations the *display time* and *world time* are directly related. Display time is the moment in time a viewer sees the animation. World time is the actual moment in time the depicted phenomena took (or are taking) place. Non-temporal animations have no direct relationship between display time and world time, but to some other aspects of the data (e.g. thematic attributes). Non-temporal animations can be subdivided into animations that represent successive build-up and animations for changing representation (Kraak, 2007). Animations that represent successive build-up are used to explain changes in location or attribute with a fixed temporal attribute by showing subsequent map layers; it explores the relationships between different map layers. Animations for changing representation provide viewers with an extensive look at a particular data set. In this type of animation, some data are depicted by different way of graphic representation (e.g. blinking effects in animation) while the location, attribute and time of data are fixed (Kraak, 2007).

The animated map, as an approach for visualizing uncertainty, is applicable to many applications. The animation approach is preferred in this research for three purposes. First, Köbben and Yaman (1995) assumed that the dynamic visualization variables will only provide favorable results in cartographic animations when combined with the graphic variables. Therefore, animation can employ the dynamic visualization variables (such as frequency or duration) to enhance the visibility of uncertainty and fuzziness embedded in the data by creating change effect in the displayed data during the display time of a running animation. The second purpose is that animation allows the users to control the representation by interaction functions. The third purpose is to draw attention of users to features present in the data.

Spatial planning is about creating a suitable environment for the future. Animation is expected to improve the visual representation of spatial planning maps by better indicating uncertainty and fuzziness aspects of data in this research. Several studies have addressed the visualization of uncertainty in animated maps which are discussed in chapter 3.4.3. However, while most studies focus on uncertainties or fuzziness of locations or attributes in various thematic maps, no attention has been paid to representing these aspects in spatial planning maps.

3.4. Visualizing geographical information uncertainty and fuzziness

Visualization of geographic information uncertainty and fuzziness has been a subject of increasing attention from researchers since the beginning of 1990s. Applying appropriate visualization techniques could provide more understandable (spatial and temporal) information of fuzziness and data uncertainty (van der Wel et al., 1994). A number of visual methods have been suggested and used for the visualization of uncertainty and fuzziness. Some methods start with Bertin's (1983) visual variables and their static and dynamic extensions (MacEachren, 1992; McGranaghan, 1993; van der Wel et al., 1994). Other methods have worked on the development of interfaces that allow users to manipulate uncertainty as needed.

The discussion of visualization methods below is divided into three subsections. First, fundamental aspects of visual representation are considered, with a focus on the application of combinations of graphic variables and their modifications and extensions. Secondly, several approaches that present uncertainty by different additional graphical objects are reviewed. Thirdly, the dynamic representation for uncertainty visualization is described, with dynamic interpreted to include animated (e.g. blinking) and interactive representations.

3.4.1. The application by means of graphical variables and their extension

Basic methods of visually representing uncertainty are available through direct application of Bertin's (1967; 1983) graphic variables and their modifications and combinations. Beard, Clapham, and Buttenfield (1991) suggested size, shape, and colour (hue) as more useful variables for representing uncertainty in point and line data, while suggesting colour value, saturation, and possibly size and shape for representing uncertainty in continuous data. Davis and Keller (1997) concluded that the best way to statically represent uncertain information are using colour hue, colour value, and texture. MacEachren (1992) considered *colour saturation* as "the most logic one to use for depicting uncertainty". He proposed to use saturated hues for map elements with a high level of certainty, while correspondingly less saturated colours for less certain information (see Figure 3.4 (a)). Colour saturation can be applied in bivariate maps which means thematic data and uncertainty are represented together in "one" visualization. For example, in a land classification map the different hues can be used to depict different land classes while colour saturation of hue indicates the uncertainty of classification result. Therefore, both the classification categories and their uncertainty can be represented in one map. Brown & van Elzakker (1993) argued the importance of colour saturation in its application to represent uncertainty in addition to attribute information in bivariate map. They also discussed the practical limitations on the use of saturation to signify uncertainty, such as low saturated colours may be difficult to distinguish from each other. Jiang (1998) suggested that low saturation can be used to indicate the fuzziness of a spatial region, because the low saturation regions have a pastel appearance. Van der Wel et al. (1994) used a continuous scale of grey tones (i.e. colour *value*) to visualizing fuzzy class boundaries on a map. The result creates a perception of focused and less focused areas which can correspondingly be understood as certain and less certain areas. Jiang et al.(1995) proposed a modified HLS (hue, lightness, saturation) colour system to display nominal categories by hue, data values by saturation and uncertainty by lightness variations, and it was applied in fuzzy overlay operations for visualizing fuzziness. Hengl (2003) presented a similar method using hue, saturation and intensity colour models to represent uncertainty associated with spatial prediction of continuous and discrete variables in soil and landform mapping. In Hengl's method, uncertain data appear more white or "pale" with increasing magnitude of uncertainty. These above researches all show that the three dimensional colour attributes play an important role in signifying uncertainty. Therefore the three dimensional colour attributes are certainly useful to cope with visually representing uncertainty.

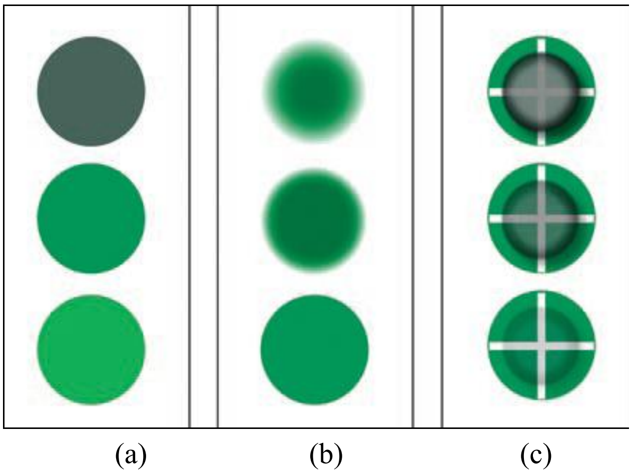


Figure 3.4 Point symbol sets depicting uncertainty with variation in (a) saturation, i.e., colours vary from saturated green-bottom to unsaturated-top; (b) crispness of symbol edge; and (c) transparency of symbol. In (c), transparency is applied to the smaller symbol in the foreground (source: MacEachren et al., 2005).

MacEachren (1992) addressed the potential of three other graphic variables to depict uncertainty (see also Section 3.2.1). These were *crispness*; *resolution* and *transparency* (initially termed *fog*) which are subdivisions of *clarity (or focus)* and which are valuable for the visualization of uncertainty. *Crispness* depicts uncertainty through making the map element boundaries fuzzy; the contrast between objects and the fuzziness of boundaries determines the magnitude of uncertainty (see Figure 3.4 (b)). *Resolution* translates to a grid size at which raster data can be displayed or vector data can be plotted. High resolution results in clear geographic information portrayal and is, therefore, suitable to represent certain information. By contrast, low resolution is better to depict uncertain information. MacEachren (1995) considered resolution as the most effective visual variable to represent geographic base information (such as boundaries) on which the thematic information is plotted. *Transparency* employs fog floating above data to obscure the user's view in depicting uncertainty (see Figure 3.4 (c)); the transparent and clear atmosphere shows certain while the cloudy atmosphere which makes data representation hardly to see, indicates uncertain information. In contrast to transparency, Drecki (1999; 2002) proposed an *opacity* method because he argued that it was more logic to consider opaque objects as the certain one. Therefore, in his opacity method, the highly transparent objects indicate uncertainty while less transparent objects are considered as certain ones. Compared to MacEachren's transparency in Figure 3.4 (c), the bottom point should be considered as uncertain if Drecki's opacity method is assumed, while in MacEachren's transparency method, the top one should be selected to display uncertainty. The above four methods employ different visual variables i.e. crispness, resolution and transparency to signify uncertainty. All of them indicate immediate and intuitive contrast between certain and uncertain information with the variation in these visual variables involved. Although it can not provide precise values of uncertainty, the user can distinguish different levels of uncertainty. They are suitable to consider as alternative methods in this research to depict uncertainty and fuzziness in spatial planning maps.

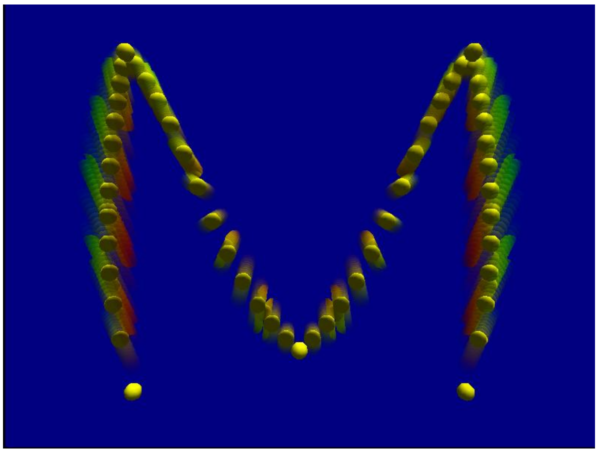


Figure 3.5 Motion blurring to indicate uncertainty. (source: Pang et al., 1997)

Blurring is the "removal of spatial high frequency details from information" (Russ, 1999; Brown, 2004). These high frequency details are used to represent fine information. Through removing them, the ability of the viewer to recognize fine features is reduced, and therefore uncertainty as to its contents is produced. Blurring looks similar to MacEachren's *transparency*. However, unlike MacEachren's *transparency* which applies a fog to obscure the map theme and produce a transparent environment, blurring can be considered as an interpolation scheme which smears the boundary between two values. It means that blurring can insert data values between two positions along a data dimension; therefore it can be applied to some graphic variables such as colour saturation and size via decrease of the sharpness of the boundaries between the values in data dimension (Brown, 2004). An example of the difference between transparency and blurring is the application on colour hue. Applying transparency on colour hue needs adding a fog on top of the hue and makes it difficult to see. However, using blurring to hue can insert some medial colour hue between the original colour hues, such as adding yellow between red and green. An example of blurring application was provided by Pang et al. (1997) in which motion blurring was used in animation to indicate the range of motion paths (see Figure 3.5). Blurring is recognized as an effective method for signify uncertainty, because viewers intuitively associate such visual representations with data uncertainty (Johnson & Sanderson, 2003; Brown, 2004; Griethe & Schumann, 2006). Therefore blurring is often applied in current researches (e.g. Pang et al., 1997; Botchen et al., 2005).

The above approaches to visualizing information uncertainty are centered on the use of graphic variables and their modifications and extensions, such as colour saturation, crispness, resolution and transparency (MacEachren, 1994b; Drecki, 2002). Of these graphic variables, colour saturation does not need further exploration because it has been discussed and applied by many researchers in many application fields. However, most of the studies are applied in a static way. Therefore, the effect of colour saturation combined with dynamic visualization variables will be tried and tested in this research. Blurring and transparency will be further explored to represent the different fuzzy and uncertain data in this research. The six basic graphic variables will assist to better make use of colour saturation, blurring and transparency.

3.4.2. Integration of additional graphical objects

This section presents uncertainty by employing different additional graphical objects. Quite common are *glyphs*. Pang (2001) and Pang et al. (1997) described their application: it are compound point symbols as an alternative method of visually representing geographic data in addition to uncertainty. Glyphs are graphical objects through which multiple graphic variables can be manipulated simultaneously (see Figure 3.6), they encode information through their colour and/or shape/size. Figure 3.6 shows that vector field with derived magnitude and directional uncertainty information are visualized by vector glyphs (Pang et al., 1997). Pang suggested that glyphs are useful for representing uncertainty. However, he also cautioned that glyphs can become visually overwhelming. Wittenbrink et al. (1996) also used glyphs for visualizing uncertainty in vector fields. Their work concentrated on designing glyphs to convey the uncertainty in both orientation and magnitude.

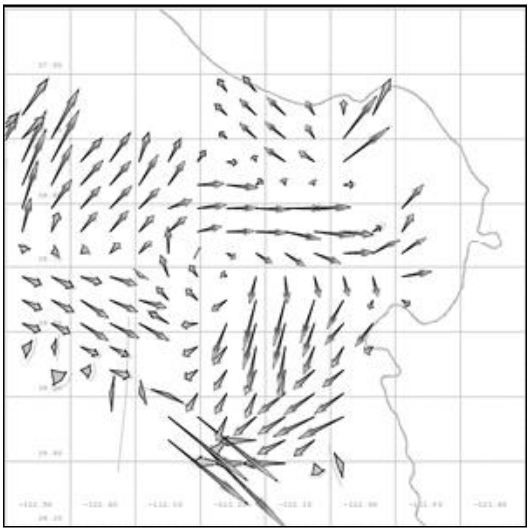


Figure 3.6 Uncertainty vector glyphs (arrows) over Monterey Bay indicate magnitude and directional uncertainty in a flow vector field (source: Pang et al., 1997)

More approaches are isosurfaces with an introduced thickness indicating spatial uncertainty (Johnson & Sanderson, 2003), or an overlaid grid with varying thickness, sharpness, noise or transparency of grid lines to indicate local uncertainty (Cedilnik & Rheingans, 2000).

3.4.3. Dynamic representations for uncertain information

In a dynamic approach, uncertainty can be related to the display time of thematic information on a monitor screen. To represent uncertainty in a dynamic way, methods like blinking, interaction in which dynamic visualization variables and other animation techniques involved are described below.

Among the dynamic representation methods, one idea is that users can control the uncertainty or fuzziness by employing *interaction*. Howard and MacEachren (1996) proposed uncertainty representation by means of users control. In this approach, the visualization only depicts data, but allows users to control which data are shown or are not shown clearly. A known example is the “clickable map” where uncertainty can be represented only by mouse interaction such as clicking (van der Wel et al., 1998). More recently, Lucieer et al. (2004) utilized interactivity to develop an exploratory visualization environment to enable the analysis of classification of remotely sensed imagery and related uncertainty.

Animation techniques can assist to represent uncertainty or fuzziness. A typical example of animation is the *blinking* effect which is created by employing frequency or duration of the display time of map features, usually proportional to their fuzziness or uncertainty. Frequently blinking objects on the screen can be used to indicate high uncertainty values while more stable displayed information represent less uncertainty values (Fisher, 1994). Fisher (1993) illustrates a complex *blinking* effect by giving an example of the soil grid cells which change their colour according to the proportion of being assigned to one of the existing soil classes. This approach focused on direct representation of uncertainty by duration, i.e. long duration in same colour for high certainty of classification.

Other *animation techniques* can also be applied to visualize uncertainty. MacEachren (1992) used sequential alternating presentation as a method for presenting uncertainty. Bastin et al. (2002) proposed a sequences animation to depict fuzziness of categorical data classification. Ehlschlaeger et al. (1997) focused on animated visualization of the impacts of elevation certainty. The focus is on optimal path calculations based on an array of 250 possible DEM configurations. This animation presents sequences of complete realizations rather than animated sequences of one category at a time.

Shepard (1994) proposed animated representations for use time-varying symbolism behavior, in which symbols vary in display time in animation, such as symbol blinking or motion/positional change, to visualize geographic data. Although he did not apply the time-varying symbolism behavior in the uncertainty or fuzziness domain, his framework seems potentially useful. Therefore, the time-varying symbol will be applied and evaluated in this research as well.

The presented techniques provided an overview of the possible visualization of uncertainty or fuzziness. The decision on which of these techniques to choose strongly depends on the intended goal. In this research, the interaction technology will be applied to allow user control of the display of uncertainty and fuzziness.

3.5. Evaluation of uncertainty and fuzziness displays

Most research on uncertainty visualization has focused on developing representation methods or theories or software applications. Few have been done to empirically evaluate whether the proposed applications or theories work (MacEachren et al., 2005). Key empirical contributions made are described below.

Schweizer and Goodchild (1992) examined the effectiveness of colour bivariate maps which represented quantitative data as saturation and reliability of those data as colour value. They found that colour value was not effective as a method for depicting data reliability when value and saturation are used together in bivariate maps. They surmised that the problem was that people do not distinguish variations in colour value and saturation independently. With this finding, the colours selected for depicting fuzziness and uncertainty in spatial planning maps in this research will only use either saturation or value, but not both, to depict uncertainty in order to assurance the effectiveness of the tests already executed.

Evans (1997) carried out a detailed evaluation of uncertainty displays. She assessed four methods of depicting data uncertainty on land use satellite (raster) images: (1) two static separate maps, one for the data while another one for the metadata, (2) A colour bivariate map showing both the data and the uncertainty information (“static” integrated method) (3) An animation of alternating frames of the land use map and the uncertainty map (“flickering” map), and (4) interactive “toggling” between the data and data uncertainty information. The results showed that subjects both performed best with the “static” integrated display and the “flickering” map. The separate map of data reliability was not effective due to the lack of continuity in the classified pixels. The interactive “toggling” method was also not as efficient as the combination methods. The result also indicated that there were no significant differences between experts and novices.

The “flickering” method was originally suggested to be suitable for uncertainty representation by MacEachren (1995). In subsequent research, Blok et al. (1999) designed an animated representation using the “flickering” method. In their animation, changing geomorphologic objects are alternated with objects and fuzziness. This representation is comparable to Evan’s method except that it is applied for temporal data. But they did not investigate the effectiveness of the method.

Leitner and Buttenfield (2000) investigated the impact of including attribute certainty information in map displays for spatial decision support. These empirical tests focused on assessing different visual variables (value, texture and saturation) for encoding certainty data by looking at timing, correctness (accuracy) and confidence of two locational decisions. They found that the addition of attribute certainty information in maps helps to make correct responses for an easy decision, if either lighter (colour) value or finer texture is used to display more certain information. The unexpected result is that the darker (colour) value is less prominent in the representation of more certain information than a lighter (colour) value. The results also indicated that adding certainty clarifies rather than complicates a map display. These findings provided the practical support to this research by indicating that adding uncertainty and fuzziness representation in spatial planning maps helps users to make better spatial planning decisions.

Drecki (2002) evaluated the effectiveness of the visual methods applied to represent uncertainty in land cover classifications. He examined five different uncertainty displays. They included colour saturation; opacity; squares; blinking and 3D reliability surfaces. Drecki's empirical comparison of these methods found the squares method to be the most effective means of visualizing uncertainty, followed by opacity, blinking, 3D reliability surfaces, and colour saturation, in descending order. The procedures and results from these empirical tests will provide the guideline for this research.

3.6. Summary

The issues of visually representing uncertainty and fuzziness are discussed in this chapter. Research is still needed on the different effects of various combinations of graphic and dynamic visualization variables in spatial planning maps. Appropriate selection of representation variables and a good balance between data and fuzziness/uncertainty needs to be considered. The variables selected for this research include Bertin's six visual variables, colour saturation, blurring, transparency and four dynamic visualization variables. The visualization method is narrowed down to interactive animated maps. The approaches will be compared and evaluated to make sure which ones are more appropriate in the case study selected.

4. Conceptual framework

4.1. Introduction

After an investigation into sources and aspects of uncertainty and fuzziness in spatial planning maps in Chapter 2, how uncertainty and fuzziness aspects can be visually represented is described in Chapter 3. The research described here is confined to animated representations, more particularly to the ways in which graphic and dynamic visualization variables can be used to visually represent uncertainty and fuzziness aspects in spatial planning maps. Uncertain and fuzzy planning objects are currently represented by crisp and static cartographic symbols in spatial planning maps. Animated cartographic symbol behaviour, for example the behaviour that was initially proposed as time-varying cartographic symbol behaviour by Shepard (1994), in relation to uncertainty and fuzziness aspects of the planning objects, will be addressed in Section 4.2. Section 4.3 will attempt to establish a conceptual framework for the use of animated cartographic symbols to represent uncertainty and fuzziness aspects in spatial planning maps. The ultimate aim is to use the conceptual framework to design and implement a prototype that is able to increase the user's awareness of the uncertainty and fuzziness in an effective way.

4.2. Animated cartographic symbols

Shepard (1994) proposed time-varying symbolism behaviour which means that symbols vary in display time in geographical data visualization. He identified five fundamental temporal parameters to implement time-varying symbolism behaviour in maps. His temporal parameters are *timing*, *duration*, *motion/positional change* (e.g. oscillating symbols), *temporal pattern (i.e. blinking)* and *variations in graphical appearance*. In terms of dynamic visualization variables, timing corresponds to the moment of display in this research, motion/positional change and blinking can be considered as regularly repeating variations in which frequency plays a role, and variations in graphical appearance happen in display time, so they can also be characterized in terms of additional dynamic visualization variables (Blok, 2005).

In static maps, cartographic symbol appearance is controlled by the use of graphic variables. In animated maps, the graphic variables may be made to vary in display time by means of using dynamic visualization variables to reflect attributes of the features (Shepard, 1994). The planning objects are currently represented by static cartographic symbols (such as point and arrow symbols) in spatial planning maps, their uncertainty or fuzziness information can not be perceived from these cartographic symbols. Time-varying cartographic symbol behaviour, here further referred to as *animated cartographic symbols*, can be used to represent uncertainty and fuzziness aspects of the planning objects in individual animation frames.

Changing basic graphic variables including location, size, value, grain (texture), colour (hue), orientation and shape and their extensions including colour saturation, transparency and blurring can be used to represent animated cartographic symbols. Besides the graphic variables, dynamic visualization variables also play an important role for designing animated cartographic symbols. Animated cartographic symbols need to be implemented in display time that means that the dynamic visualization variables will be involved to make the changes visible in the temporal dimension of the animated representation. An example of using the dynamic visualization variables is the application of different moments of display in representing size change (see Figure 4.1).

Blok (2005) provided a definition of four dynamic visualization variables (see section 3.2.2); the dynamic visualization variables in animated cartographic symbols which are discussed here are based on these definitions. Moment of display implies the moment of change of the graphic variables in the representation in display time. Order is a structured sequence of change of the graphic variables. As shown in Figure 4.1, the order of size change is size increasing, then further decreasing to make an effect of size fluctuation. Different order of changes of the graphic variables produces different animated cartographic symbols; choosing a principle or criterion of order is based on the desired effect. Duration indicates the length of display time during which a state of the graphic variables in an animation is visible, while frequency implies the number of identical changes of the graphic variables per unit of display time. Some animated cartographic symbols, such as location oscillation and size fluctuation, can be implemented at different frequency. Frequency also can be used in loops of animation which provides an option to view animated cartographic symbols once again (Blok, 2005).

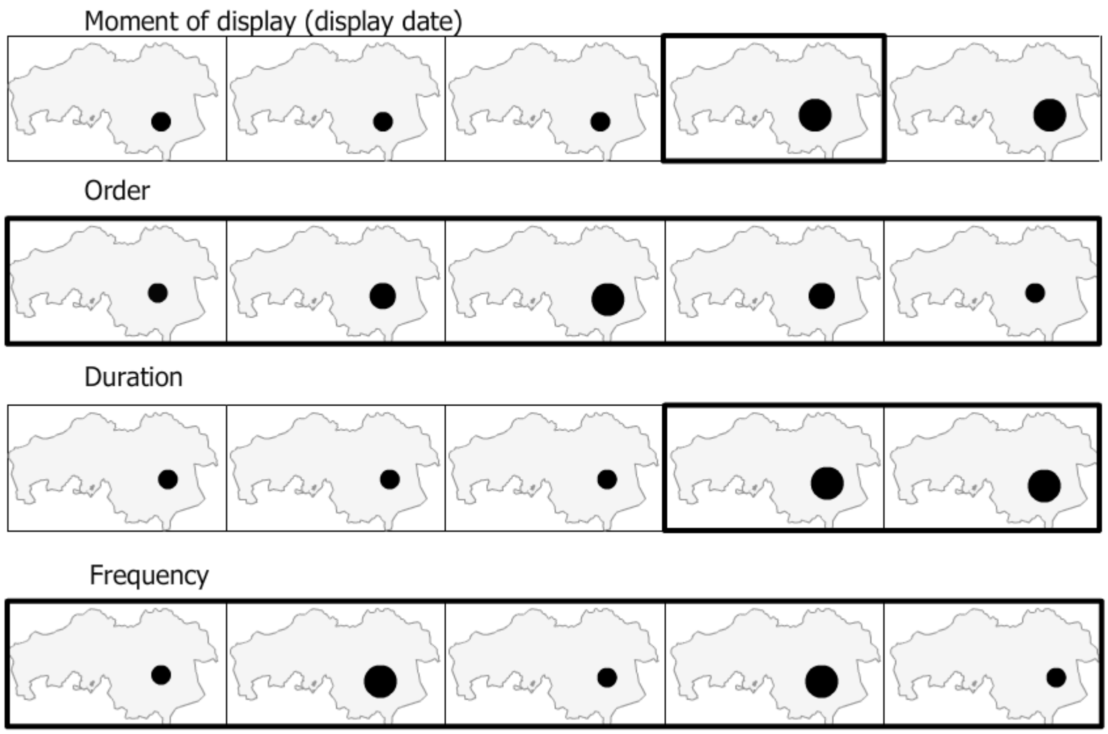


Figure 4.1 Dynamic visualization variables in representation of size change (Modified from Blok, 1998)

Some examples of animated cartographic symbols by changing the graphic variables in display time are shown in Figure 4.2.

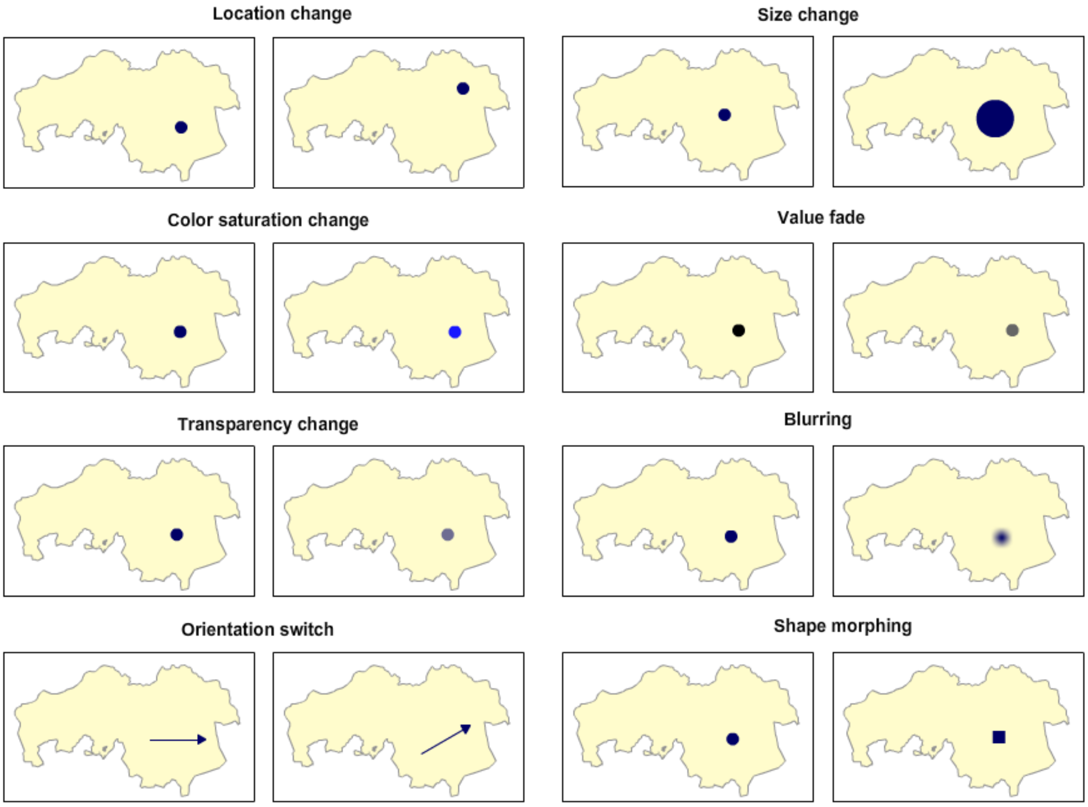


Figure 4.2 Animated cartographic symbols by changing graphic variables in display time

Five aspects of uncertainty and fuzziness in spatial planning maps (location, boundary, orientation, size and shape) are distinguished in Chapter 2. Some animated cartographic symbols are suggested to deal with each of these aspects (see Table 4.1).

Table 4.1 Animated cartographic symbols using the graphic variables in display time in representations of aspects of uncertainty and fuzziness

Uncertainty and fuzziness aspects	**Animated cartographic symbols using the graphic variables in display time**		
Location	Location change	Size change	
Boundary	Colour saturation change Value fade	Transparency change	blurring
Orientation	Orientation switch		
Size	Size change		
Shape	Shape morphing		

Locational uncertainty indicates that the precise location of planning objects is not known. Two animated cartographic symbols using graphic variables varying in display time are suggested to represent locational uncertainty and fuzziness: location change (such as a regular oscillating motion) and size change (such as size fluctuation). Locational change of an animated cartographic symbol can be used to represent the possible locations of a planning object, while size change can be used to represent a possible locational region of a planning object. The reason why choose these two animated cartographic symbols is logical and obvious since both of them symbolize the uncertain locations of a planning object.

Boundary uncertainty and fuzziness are involved in both fuzzy and incompletely defined planning objects. An example is a noise boundary which is shown as a solid noise contour in one noise level on spatial planning maps currently. However, in reality a noise boundary is continuous. Therefore, the current visual representation of boundaries of planning objects does not indicate the level of the uncertainty and fuzziness. Suggested animated cartographic symbols, including varying colour saturation, value fade, transparency change and blurring, aims at better describing uncertain and fuzzy boundaries of planning objects. As discussed in Section 3.4.1, colour saturation, value, transparency and blurring were applied in static visualizations of uncertainty by researchers (such as MacEachren, 1992; van der Wel et al., 1994). In this research, these graphic variables are employed to represent uncertainty and fuzziness in an animated representation.

Currently, the orientation of some line planning objects in spatial planning maps is only an indication, it is not precisely represented. Orientation switch can be used to indicate the corresponding orientation range in reality. These animated cartographic symbols help spatial planners to be aware of the orientation uncertainty.Size and shape of planning objects are sometimes uncertain because information about these aspects is not known or supposed to be determined later. Two animated cartographic symbols including size change and shape morphing are suggested to describe a more realistic planning object by representing the potential maximum size and possible shape of planning objects.

In the design of animated cartographic symbols we need to make use of graphic and dynamic visualization variables together. From a design perspective, an effective animated cartographic symbol depends on ways in which the dynamic visualization variables are linked to graphic variables.

4.3. A conceptual framework for representing uncertainty and fuzziness

A conceptual framework for the use of animated cartographic symbols to represent uncertainty and fuzziness in spatial planning maps is shown in Figure 4.3. A prototype for the animated representation of uncertainty and fuzziness of planning objects will be designed and implemented based on the concepts indicated in the conceptual framework.

The components included within the conceptual framework are the graphic and dynamic visualization variables, animated cartographic symbols and the aspects of uncertainty and fuzziness, these components should be incorporated in an animated representation. A combination of the graphic and dynamic visualization variables can create animated cartographic symbols and effective animated cartographic symbols can be used to represent five aspects of uncertainty and fuzziness of planning objects. A planning object which may have some or all of the aspects of uncertainty and fuzziness can be represented by a combination of animated cartographic symbols. For example, a fuzzy point planning object includes locational, boundary, size and shape uncertainty. Locational uncertainty can be represented using locational change, boundary uncertainty can be indicated by boundary blurring, while size and shape uncertainty can be represented by size change and shape morphing. Therefore, the combination effect of these animated cartographic symbols together can reveal the uncertainty information of the fuzzy point planning object.

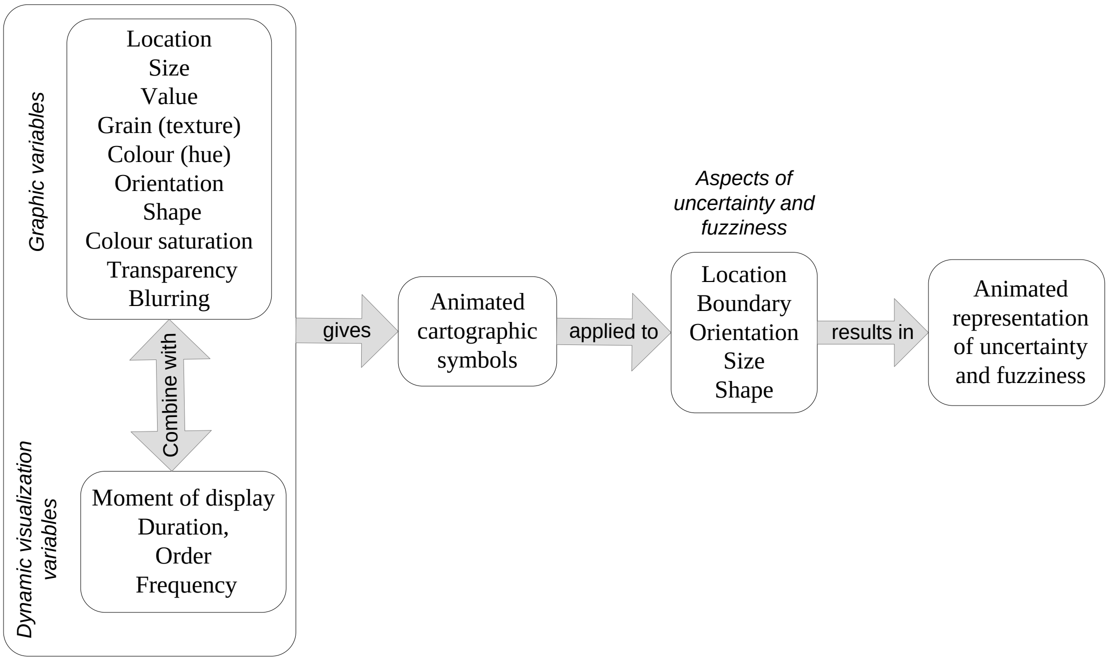


Figure 4.3 A conceptual framework for animated representation of uncertainty and fuzziness of planning objects

4.4. Summary

By using graphic and dynamic visualization variables, animation can be used to represent uncertainty and fuzziness. A proposed conceptual framework constitutes a general formalization within which the animated cartographic symbols can be designed using graphic and dynamic visualization variables which represent the aspects of uncertainty and fuzziness in spatial planning maps. It is assumed that representing the aspects of uncertainty and fuzziness using animated cartographic symbols as suggested in this chapter can help spatial planners to be aware of the real situation of the planning objects.

5. Prototype design and implementation

5.1. Introduction

In Chapter 4, after conceptually defining the animated cartographic symbols, a conceptual framework for representing uncertainty and fuzziness of planning objects is designed. The conceptual framework provided the starting-point for the development of a prototype for this research. First, Section 5.2 highlights the case study data used in this research. Section 5.3 describes the initial prototype design. The general considerations are introduced first in Subsection 5.3.1, this is followed by a description of the prototype interface (Subsection 5.3.2) and Subsection 5.3.3 illustrates and specifies the animated cartographic symbols. Section 5.4 indicates how the prototype has been implemented.

5.2. Case study data

The Noord-Brabant regional plan of 2002 (Streekplan Noord-Brabant 2002) was chosen as a case study in this research. It contains the provincial spatial strategy for the period 2002-2012. The main purpose of this regional plan is to pursue a more careful zoning of space use (Noord-Brabant, 2002). A short description of these plans is given in URL 5.1.

“The province of Noord-Brabant has approved a regional plan that incorporates modern spatial issues on 22nd February 2002. Starting point was the economic use of available space, taking into account soil conditions, water management and existing built-up areas and infrastructure. The policy regarding living and working, protection of the environment, the agricultural interests and urbanization projects all will get shape in the new regional plan and the individual reconstruction plans. Noticeably the zoning surrounding natural landscapes and housing projects in smaller villages initially met quite some resistance.” (see URL 5.1).

The Province of Noord-Brabant is located in the south of the Netherlands. It is bordered by Belgium in the south, the Meuse River in the north, Limburg in the east and Zeeland in the west (see Figure 5.1). The Noord-Brabant regional plan of 2002 includes seven regional plan maps. The first plan map: main environment structure (“plankaart 1: ruimtelijke hoofdstructuur”, see Figure 5.2) was chosen as case study data in this research for the following reasons:

- The spatial plan represents a real situation of the spatial planning, currently used in the Netherlands.
- Two sources and five aspects of uncertainty and fuzziness of planning objects are all involved in these spatial plans.
- All data including complete metadata are available in a digital atlas (Noord-Brabant, 2007, also available in URL 5. 2).
- Regional plan texts are available in URL 5.3.
- The data has also been used for other purposes in the GeO3 project.

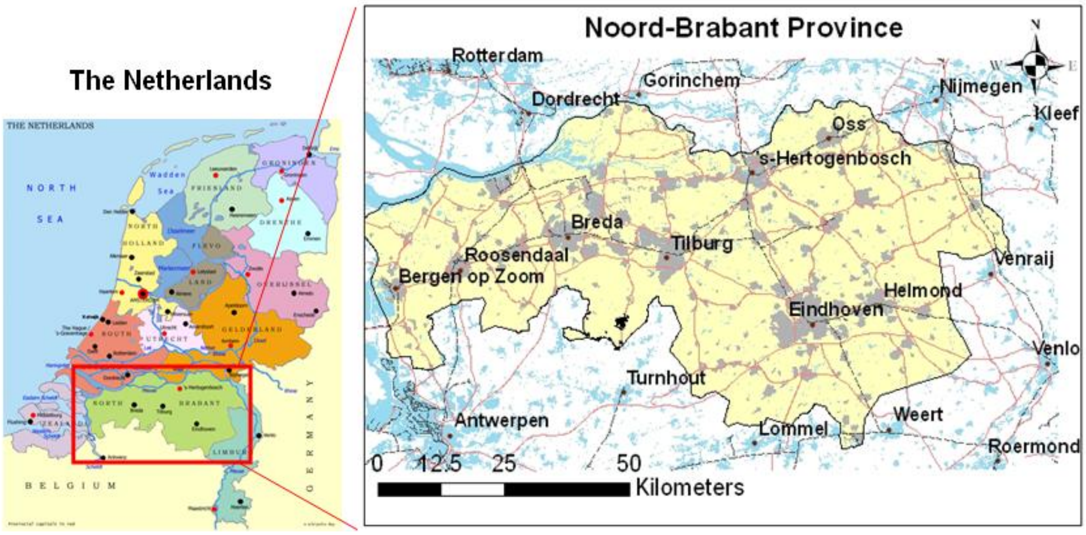


Figure 5.1 Study area: the Noord-Brabant province

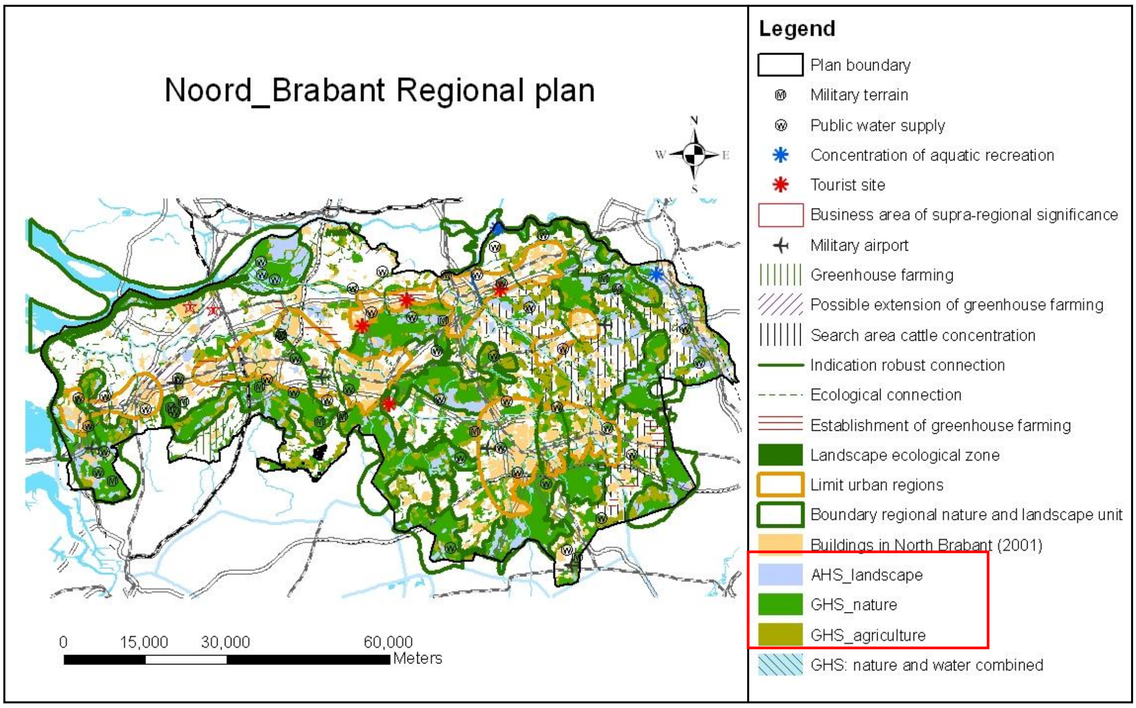


Figure 5.2 Overview of the Noord-Brabant regional plan 1

In the digital atlas of the regional plan map 1, more than 20 map layers are available. A subset of layers was selected as examples of uncertain or fuzzy planning objects in this research; the selection was made such that the sources and aspects of uncertainty and fuzziness conceptually defined in Chapter 4 are both involved. Two sources of uncertainty and fuzziness include point, line, area and continuous phenomena planning objects. The case data layers used to represent these planning objects are shown in Table 5.1, their uncertainty and fuzziness information was extracted and summarized from the Noord-Brabant regional plan text (see URL 5.3). The three map layers that are emphasized in Figure 5.2 impose some limitations on implementation plans in reality:

- GHS_nature and GHS_agriculture (GHS stands for Groene HoofdStructuur, or Main Green Structure). Their boundaries and surface are strict; they should not be occupied by other planning objects.
- AHS_landscape (AHS stands for Agrarische HoofdStructuur, or Main Agricultural Structure). AHS landscape areas sometimes might be used for other objects. In such cases, nature and landscape values should be preserved, or else compensated.

Table 5.1 Case data sets as examples of uncertain and fuzzy planning objects used in this research

<table>
<tr><th colspan="2">Sources of uncertainty and fuzziness</th><th>Case data layers used in this research</th><th>Uncertainty and fuzziness information of the case data layers</th></tr>
<tr><td rowspan="3">Incompletely defined planning objects</td><td>Point</td><td>Aquatic recreation</td><td>1. Large scale aquatic-related tourist facilities are permitted at suitable locations in Lithse Ham and Kraaijenbergse Plassen.
2. In Lithse Ham, locations on the landside of the dykes might be needed due to river policies.
3. In Kraaijenbergse Plassen, it might be needed to use AHS landscape area. In such cases, nature and landscape values should be preserved, or else compensated.</td></tr>
<tr><td>Line</td><td>Landscape ecological zone</td><td>1. The location is globally determined at 1:100.000 scale; variations up to a distance of approximately one kilometre are allowed.
2. The thickness of arrow indicates the width of the zone.
3. The width can vary in different parts of the zone.
4. Exact location, width and permissible functions will be determined in the context of implementation plans for urban regions.</td></tr>
<tr><td>Area</td><td>Greenhouse farming</td><td>1. New establishments and switch-overs to greenhouse farming are only allowed in planned establishing areas for greenhouse farming.
2. Outside planned establishing areas, farms cannot be extended in GHS.
3. Outside planned establishing areas, farms can be extended to a maximum of 3 hectares in AHS.
4. In urban regions, establishment in potentially wet areas is permissible if water management has been properly taken into account.
5. In rural regions, establishment in potentially wet areas is not allowed.
6. Establishment in groundwater protection areas is not allowed.</td></tr>
<tr><td colspan="2">Discretely defined continuous phenomena</td><td>Noise area and boundaries</td><td>1. Noise zones and boundaries (based on policies or appointments).</td></tr>
</table>

5.3. Initial prototype design

5.3.1. General considerations

One of the research objectives is to develop methods to effectively visualize uncertainty and fuzziness in animated representations by various combinations of graphic and dynamic visualization variables. A prototype, therefore, was designed to demonstrate various alternative animated representations. The aim is to use the prototype for demonstration and testing of the animated representations of different planning objects to improve their usability.

The initial idea was to convert the original cartographic symbols of uncertain and fuzzy planning objects in the regional maps into animated cartographic symbols, and then display the whole map together with the animated cartographic symbols in the same display window of the prototype. However, problems arose after building the prototype because the animated cartographic symbols could not be well and accurately displayed on the small scale map, and many animated cartographic symbols displayed together in the map may make users to become annoyed or disturbing. Therefore, a way to avoid these problems was considered, by displaying the animated cartographic symbols at a larger scale.

Subsequently, therefore, two display windows were designed in the prototype (see Figure 5.3). The left window is a map window which is for the representation of the regional planning map of the province Noord-Brabant. When user click on the uncertain or fuzzy planning objects, their animated representations are displayed in the right window (the animated representation window) at a larger scale than in the map window. Therefore, the animated cartographic symbols can be better and more accurately displayed. In addition, the animated representation window only displays the planning objects of a small regional rather than a whole regional planning map. Therefore, disturbance of excessive animated cartographic symbols can be reduced, or even be avoided.

The regional planning map of the province Noord-Brabant has more than 20 map layers. Some planning objects cannot be clearly identified in the map because different types of planning objects are overlaid in the map. This potential problem had to be taken into account in the design. Therefore, an interactive map legend was designed in which the map layers can be switched on and off by clicking on the categories in the map legend. The user would normally have an overview of the whole map and zoom in (in the prototype simulated in the animated representation window) or select a particular subset of the map layers (based on relevant tasks) to better identify the planning objects in the planning maps.

Providing detailed uncertainty information about the uncertain and fuzzy planning objects was considered as a means to allow users to better understand the animated cartographic symbols. Therefore, an uncertainty information window was also designed to display detailed uncertainty information in text about the planning objects (see Figure 5.3).

The usability of the animated representations in the prototype will be evaluated. Therefore, for each type of planning objects, two or three animated approaches were designed. A control panel which includes BACK and NEXT buttons was designed to facilitate usability testing. In addition, some animated instructions to be displayed in the map window were designed to guide users through the usability tasks later on.

5.3.2. Prototype interface

The default appearance of the prototype is represented in Figure 5.3. The *map window* is reserved for the representation of the regional planning map of the province Noord-Brabant, its legend is clickable. The control panel includes *BACK* and *NEXT* buttons, as explained above. The *uncertainty information window,* used to display detailed text about the objects, can be scrolled up and down by clicking on the arrow buttons if not all information fits in the display area of this window.

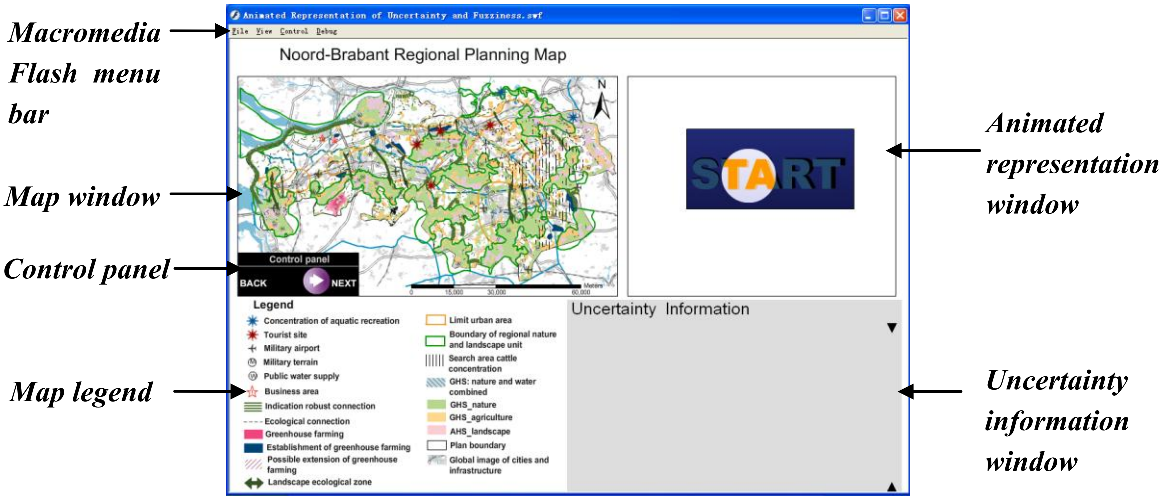


Figure 5.3 The default display of the prototype window

After clicking START and a planning object (emphasized using a black circle in Figure 5.4) in the map window, the animated representations of fuzzy and uncertain planning objects are displayed in the *animated representation window* at a larger scale than in the map window (see Figure 5.4). The *animated representations title* identifies the displayed planning object. The *REPLAY* button can be used to replay the animated representations.

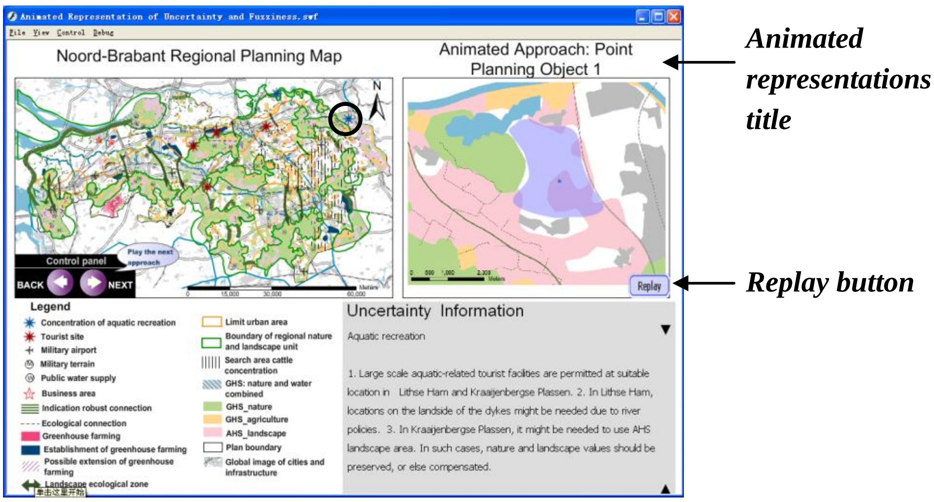


Figure 5.4 The animated representation window in use

5.3.3. Illustration and specification of animated cartographic symbols

The two sources of uncertainty and fuzziness in spatial planning maps result in four types of planning objects i.e. point, line, area planning objects and continuous phenomena. Examples of these planning objects were selected for animated representation in the prototype (see Figure 5.5). For each case, two or three animated cartographic symbols were designed taking into account the uncertainty information and the limitations of GHS nature and agriculture and AHS landscape (as indicated in section 5.2). This section illustrates and specifies these animated cartographic symbols. Three frames which are the initial, intermediate and final frame were extracted from each of the animated cartographic symbols.

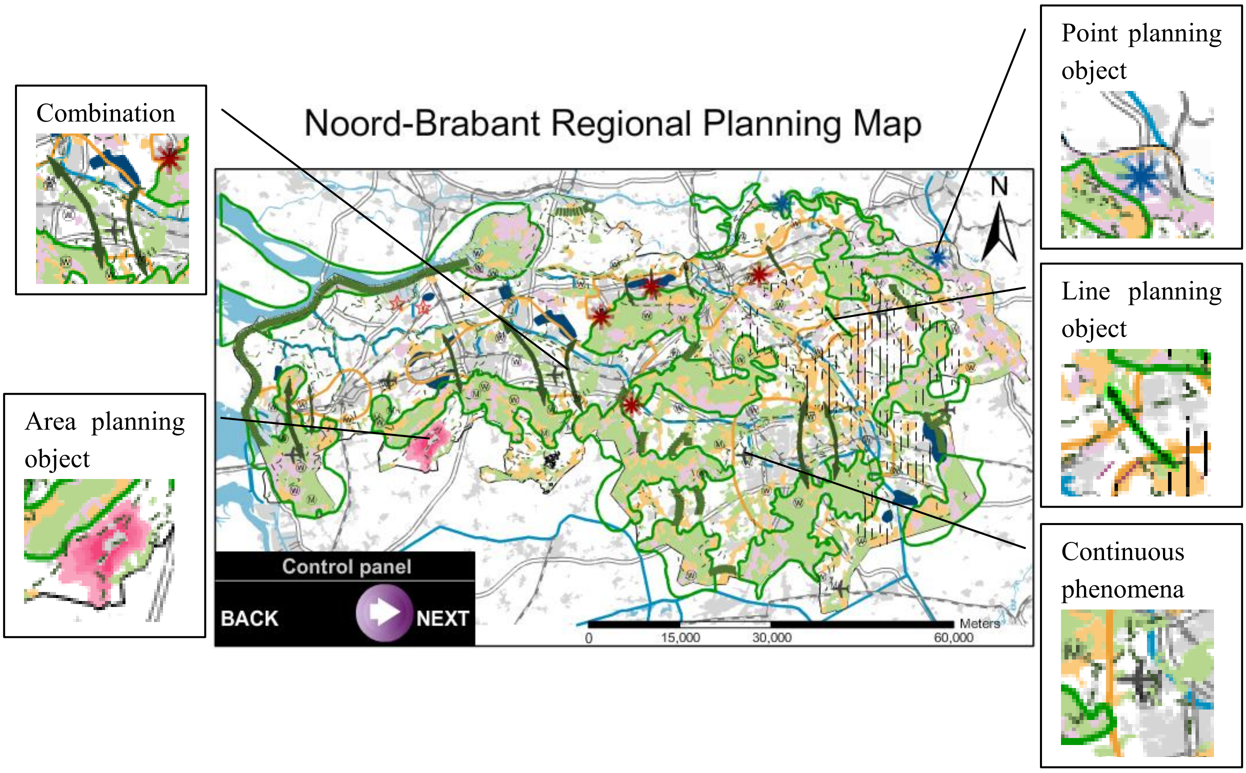


Figure 5.5 Included are point, line, area planning objects, continuous phenomena and their combination

- Point planning objects

For point planning objects, an example of aquatic recreations was selected as a case. The aquatic recreations are currently represented as blue star symbols in the spatial planning map (see Figure 5.5). According to the uncertainty information about aquatic recreations (see Table 5.1), their location, size, shape and boundary are uncertain because it is not shown on the spatial planning map, or supposed to be determined later. Two animated cartographic symbols were designed to represent the uncertainty information, as shown in Figure 5.6. The green areas in the regional planning map are GHS areas which cannot be modified, the pink areas are AHS landscape areas, in Kraaijenbergse Plassen (the area represented on the map) it is allowed to use AHS areas to develop aquatic recreation. The specification of the two animated cartographic symbols is given in Figure 5.7. The first animated cartographic symbol employs size change and shape morphing to represent the possible shape and maximum size of the aquatic recreation, while transparency changes indicate the fuzzy boundary. Uncertainty/fuzziness in zoning plans has different levels, such as certain, likely, possible and uncertain. For the first animated cartographic symbol, higher transparency means higher level of fuzziness. In the second approach, differences in colour saturation represent different fuzziness levels of boundary, size changes and shape morphing indicates the possible shape and maximum size similar to the first example. The blurring boundary of the right part of the symbol in Figure 5.6 (b) expresses that there still is a possibility to further extend aquatic recreation, but the crisp boundary of the left side of the symbol indicates that further extension is not allowed due to the limitation of the GHS nature area.

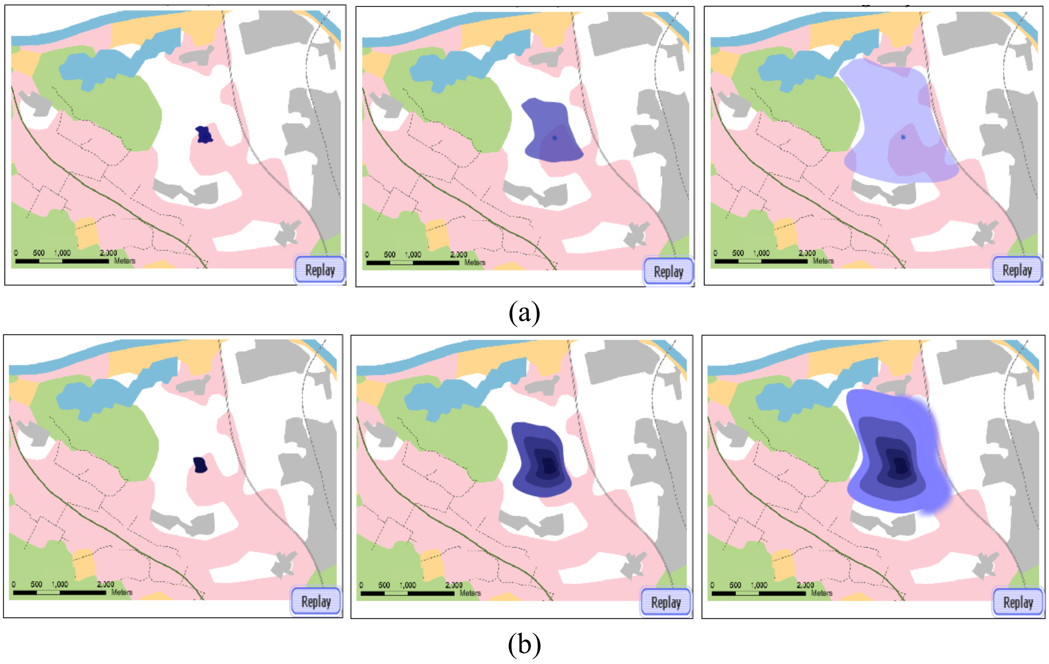


Figure 5.6 The initial, intermediate and final frames of the animated cartographic symbols of the aquatic recreation, (a) animated approach 1, (b) animated approach 2

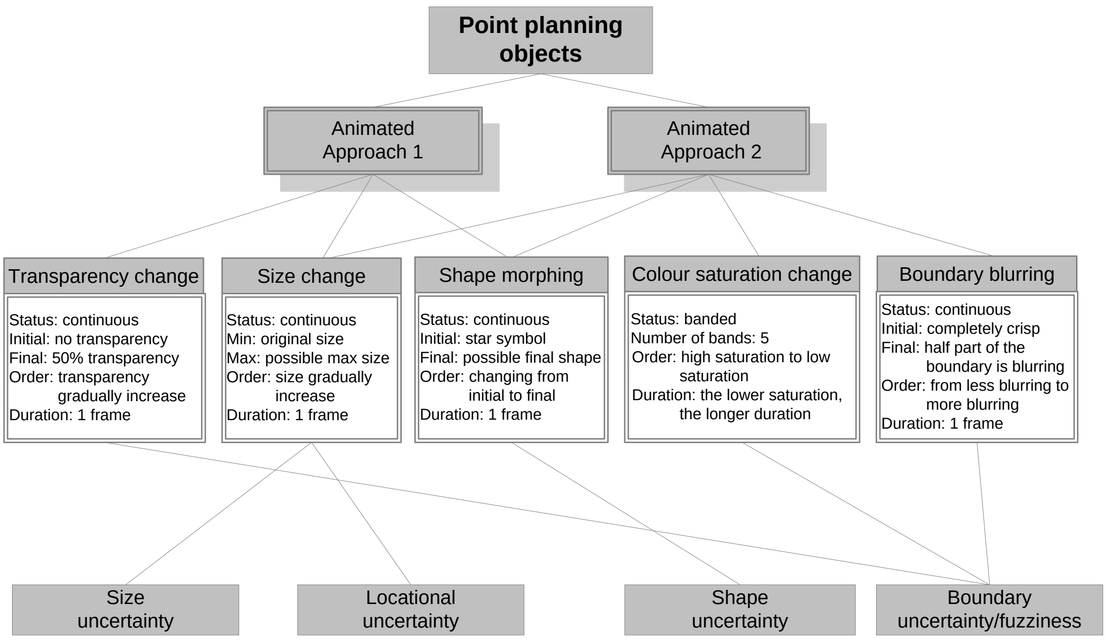
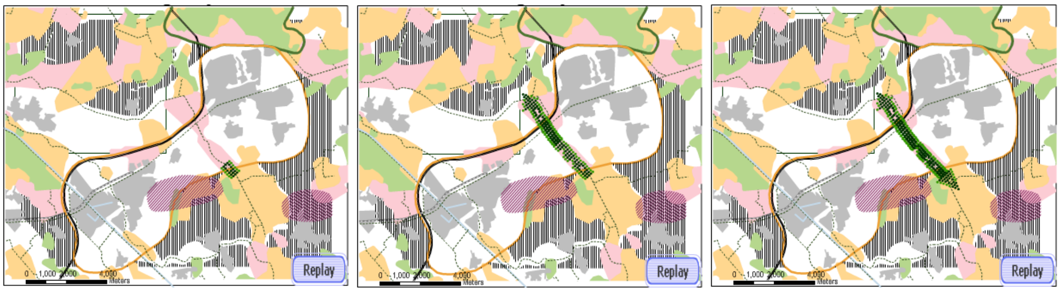


Figure 5.7 The specification of the animated approaches of the point planning objects

- Line planning objects

For line planning objects, a landscape ecological zone was selected as example. A landscape ecological zone is a green buffer zone between two urban cores in an urban region. It consists of a combination of areas for agriculture, nature and recreation, and has a binding function for adjoining rural areas (see URL 5.4). Landscape ecological zones are currently represented as green arrow symbols in the spatial planning map (see Figure 5.5). According to the uncertainty information of the landscape ecological zones as shown in Table 5.1, their exact location, size, shape and local widths/boundary are uncertain in the spatial planning map, for example, it could be a bit more to the east or to the west than on the map and the width may vary locally. Three animated cartographic symbols were applied to represent their possible shape, location and maximum size by changing size as shown in Figure 5.8; the detailed specifications are shown in Figure 5.9. The first animated cartographic symbol employs blurring boundary to indicate the fuzzy boundary. The second animated cartographic symbol uses the "stepping stone" method. Lower colour saturation of the "stepping stones" indicates a fuzzy boundary of the object. The third animated cartographic symbol uses size gradually growing from one side of the urban region to the other side, and then returning back; the transparency in the overlay indicates the fuzzy boundary of the landscape ecological zone.

(a)



(b)

(c)

Figure 5.8 The initial, intermediate and final frames of the animated cartographic symbols of the landscape ecological zone (a) animated approach 1, (b) animated approach 2, (c) animated approach 3

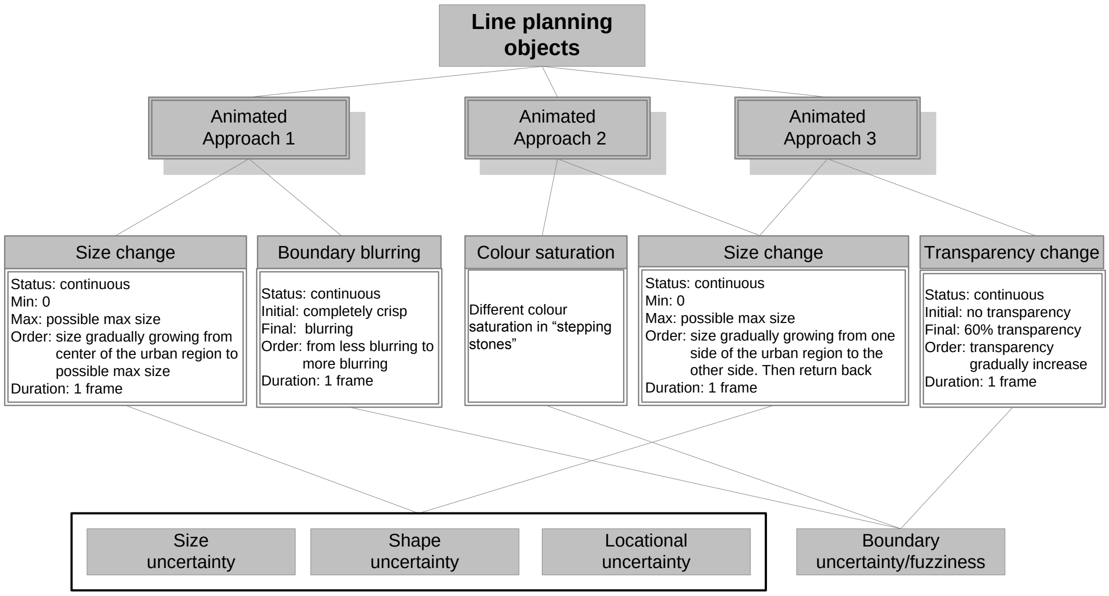
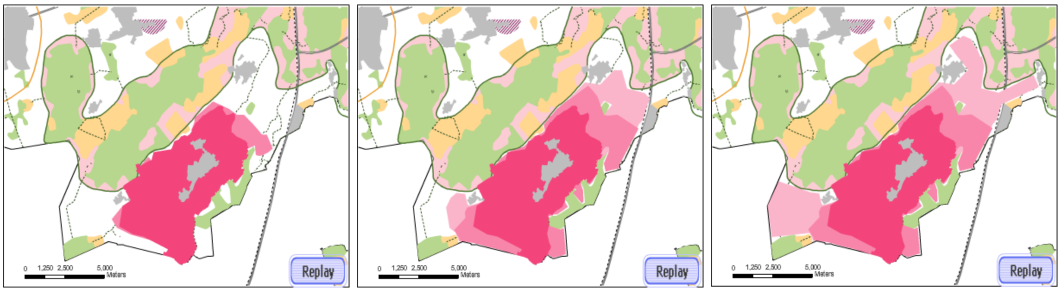


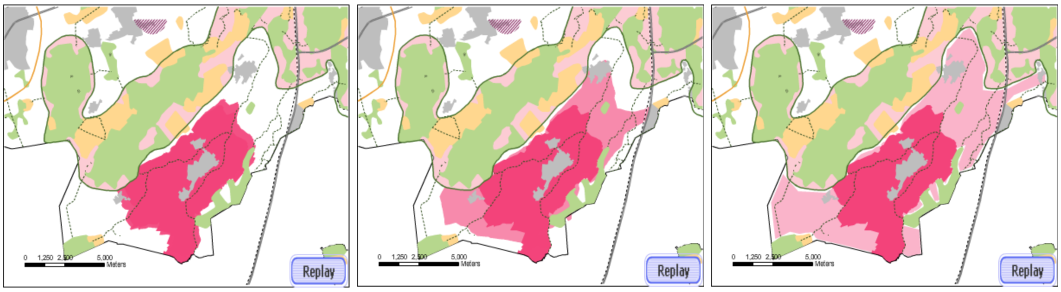
Figure 5.9 The specification of the animated approaches of the line planning objects

- Area planning objects

For area planning objects, one of the greenhouse farming areas was chosen as example (see Figure 5.5). The animated representations were influenced by the limitation of uncertainty/fuzziness information (as shown in Table 5.1): uncertain location, size, boundary and shape of the greenhouse farming (see Figure 5.10). The specification of the two animated cartographic symbols is given in Figure 5.11. In the Figure 5.10, the green lines surrounds GHS_nature and AHS_landscape area are boundaries of regional nature and landscape unit, they are limited to change where the GHS and AHS_landsacape encloses (see URL 5.3), therefore the greenhouse farming can not be developed inside the boundaries of regional nature and landscape unit. Due to this limitation, the maximum size and possible shape of greenhouse farming in this case can be determined. The first animated cartographic symbol makes use of colour saturation, shape and size change. The size change and shape morphing represent the possible location, shape and maximum size of the greenhouse farming, while the different colour saturation represents the fuzzy boundary. The greater colour saturation represents less fuzziness level. In the second approach, different degrees of transparency represent different levels of fuzzy boundary, size change and shape morphing indicates the possible location, shape and maximum size that is similar to the first case.



(a)



(b)

Figure 5.10 The initial, intermediate and final frames of the animated cartographic symbols of the greenhouse farming (a) animated approach 1, (b) animated approach 2

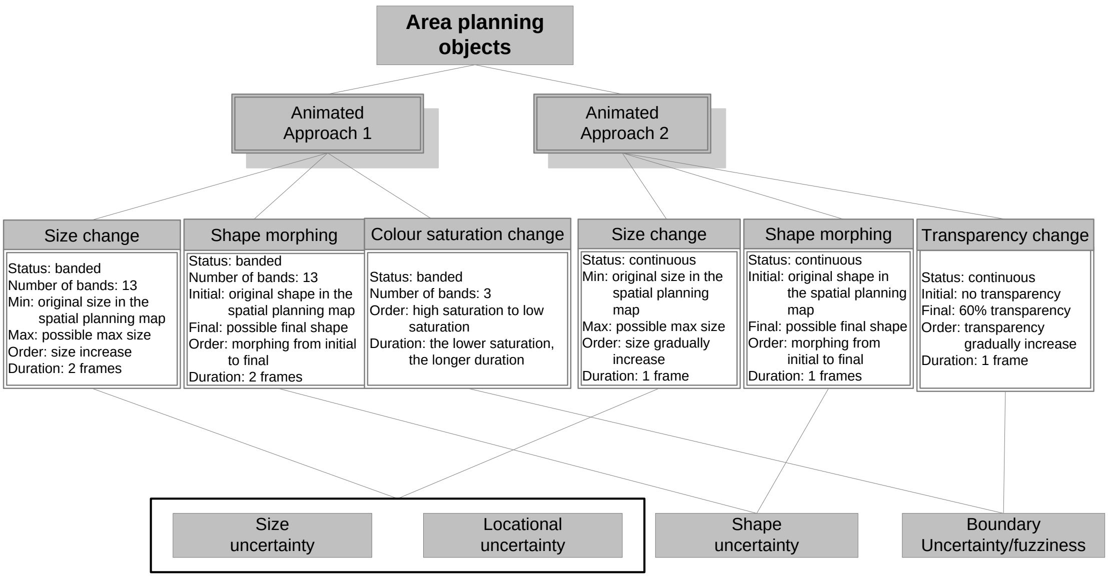


Figure 5.11 The specification of the animated approaches of the area planning objects

- Continuous phenomena planning objects

Noise zones and boundaries were selected as example of the continuous phenomena planning objects; one of the military airports was used as a noise centre as indicated in Figure 5.5. Based on policies and appointments, three noise boundaries and four noise zones were designed in an animated way (Figure 5.12). The specification of two animated cartographic symbols is given in Figure 5.13. The first approach uses blurring to indicate the location, size, shape and fuzzy boundary of the noise area, while three noise boundaries, represented by differences in colour saturation and size divide the whole noise area into four noise zones.

The second animated cartographic symbol utilizes four degrees of transparency to represent four noise zones; the largest circle indicates the whole noise area.

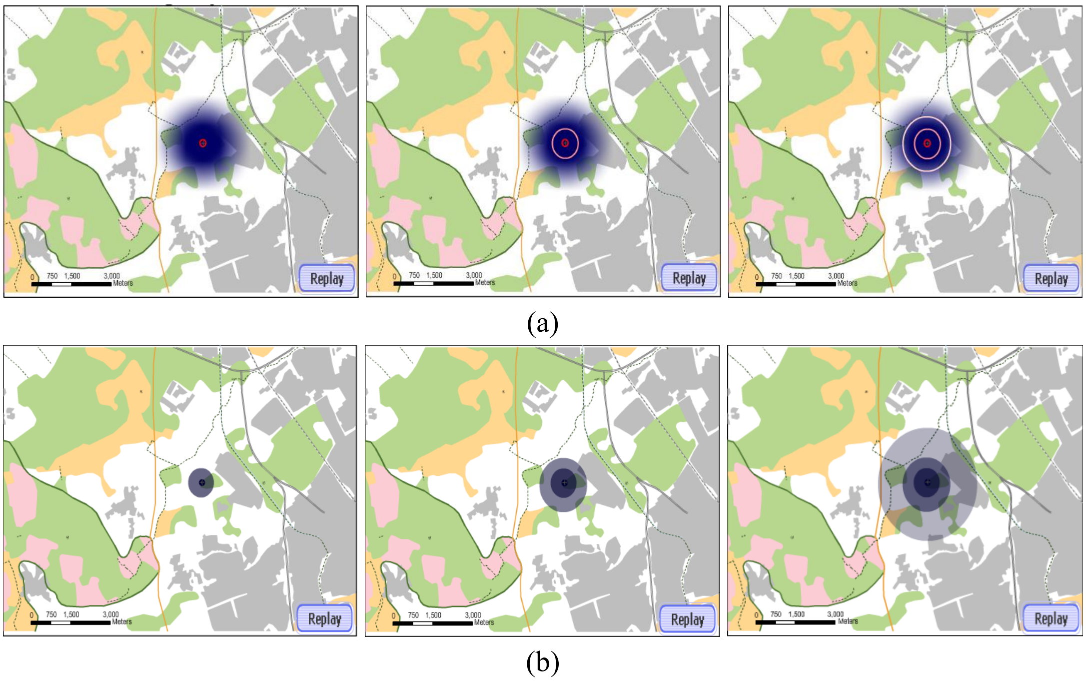


Figure 5.12 The initial, intermediate and final frames of the animated cartographic symbols of the noise zones and boundaries (a) animated approach 1, (b) animated approach 2

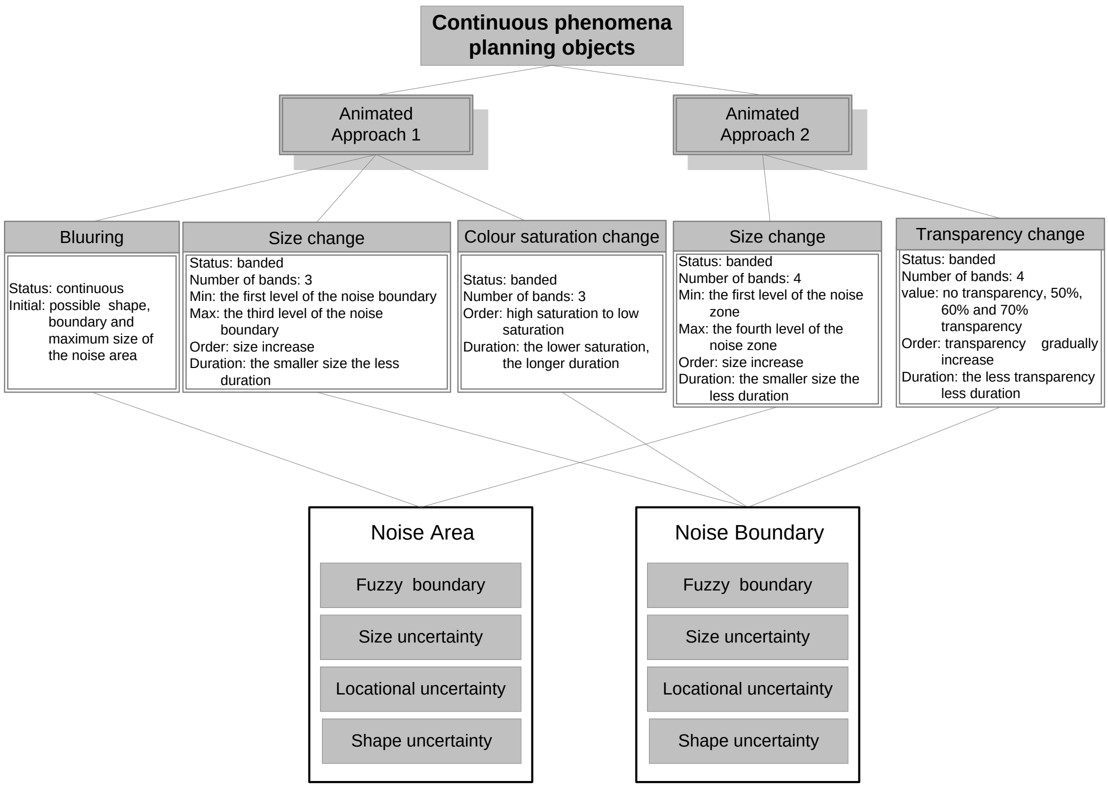


Figure 5.13 The specification of the animated approaches of the continuous phenomena planning objects

- The combination of animated planning objects

Figure 5.14 displays the combination of animated planning objects, representing uncertainty/fuzziness information. If the location of the animated planning objects is close to each other, there is the possibility of the overlay/intersection of boundaries of different planning objects. It can be understood as the boundaries of these planning objects are indicative. It warns spatial planners that if some spatial planning activity is taking place within this boundary, please apply the regulations given in the metadata, and these regulations could well be based on illustrations and specifications of the animated cartographic symbols.

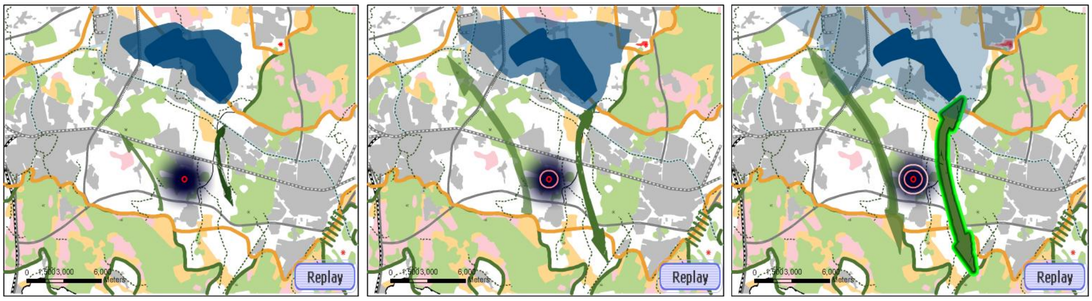


Figure 5.14 The combination of animated planning objects, together with uncertainty/fuzziness information.

5.4. Implementation

All operations and the animated representations designed above were implemented in an application using Macromedia Flash Professional 8, which is software for building interactive dynamic interfaces. Macromedia Flash software allows building high level interactive functions using Action Script as programming language.

The initial regional planning map layers of Noord-Brabant are stored in shapefile (.shp) files. The base map layers were exported in PDF format using ArcMap because Macromedia Flash software supports PDF format. Then, the map data were imported into Macromedia Flash. All the interactive legends, buttons and animated representations were made in Action Script. The size of the three application windows i.e. the map window, the animated representation window and the uncertainty information window were designed depending on the size of the computer screen and the size of the map files.

A START button was implemented to play the Flash application by clicking it. In order to facilitate the usability testing later, a display sequence of the animated representations was set up according to the sequence of the usability tasks. Users can interact with the BACK and NEXT buttons to perceive all animated representations. The prototype was published in .swf format. Many application programs support the display .swf files, such as Internet Explorer and Macromedia Flash Player.

5.5. Summary

As a case study, a regional planning map of the province Noord-Brabant of 2002 was obtained. This data was used to implement a prototype application which was designed to fulfil the conceptual framework designed in Chapter 4. The overall design is based on data characteristics and assumed convenience of users for the evaluation of the prototype. The prototype supports the display of some animated cartographic symbols to represent uncertain/fuzzy planning objects. The prototype needs to be evaluated, which will be described in Chapter 1.

6. Evaluation

6.1. Introduction

One of the objectives of this research is to select or develop a method by which the usability of uncertainty and fuzziness display in spatial planning maps can be evaluated. The evaluation was done in two phases. The first evaluation was a focus group session in which six domain experts participated. A goal of the focus group evaluation was to obtain feedback on a first design of the symbols. This feedback was on the visualization of uncertainty and fuzziness in spatial planning maps. Another goal was to discuss possible tasks for the later evaluation session. The prototype was adapted based on the results obtained in the focus group session. The second evolution was a usability testing. Nine participants from ITC, from the fields of urban and regional planning (6) and geovisualization (3) were participated in a questionnaire method.

Section 6.2 highlights the usability concept. Section 6.3 starts with a brief overview of the usability testing methods (Subsection 6.3.1); this is followed by an explanation of the selection of the methods used in this research (Subsection 6.3.2). Section 6.4 provides the detailed evaluation of the prototype in the focus group session. The procedure and participants of the session are described in Subsection 6.4.1, the results of the focus group session are summarised in Subsection 6.4.2. Then, adaptations to the prototype based on the result from the focus group session are given in Subsection 6.4.3. Section 6.4.3 addresses the questionnaire method used next in this research. Subsection 6.5.1 presents a description of goals and tasks for the test session, the next subsections describe the materials (Subsection 6.5.2), Participants (6.5.3), Procedure (6.5.4). Results of the questionnaire are described in Subsection 6.5.5. Subsection 6.5.5.1 analyses the results collected from user tasks, and usability results are analysed in Subsection 6.5.5.2. Some of the results form both evaluations are discussed in Section 6.6.

6.2. Usability

The usability issue was and is addressed as a research challenge in the context of geovisualization by the International Cartographic Association (ICA) Commission on Visualization and Virtual Environments (MacEachren & Kraak, 2001). According to usability engineering principles, in which usability testing has its roots, a product is not complete without a usability testing (Tsoene, 2004). Usability is defined by International Standardization Organisation ISO DIS 9241-11 as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” (see URL 6.1). In addition, Nielsen (1993) identified five usability measures: learnability, efficiency, memorability, errors and satisfaction. Therefore, usability measurement includes a list of measures to evaluate the product. The usability evaluation process that was conducted in this research follows the ISO definition, since it is widely accepted. Therefore, usability in this research is defined as the *effectiveness*, *efficiency* and degree of *satisfaction* with which users can perceive the uncertainty and fuzziness of planning objects using animated representations. The description of each measure is shown in Table 6.1.

Table 6.1 Description of usability measures (ISO DIS 9241-11, see URL 6.1)

Usability measures	Description
Effectiveness	The accuracy and completeness with which users achieve specified goals.
Efficiency	The resources expended in relation to the accuracy and completeness with which users achieve goals.
Satisfaction	The comfort and acceptability of use.

The ISO DIS 9241-11 standard delivered a usability framework as shown in Figure 6.1. The framework describes the components of usability and their relationship. When measuring usability, the context of use consisting of relevant characteristics of the users, tasks, equipments and environment as well as the goals of use of a product should be described. In addition, usability measures including effectiveness, efficiency, and satisfaction are also required.

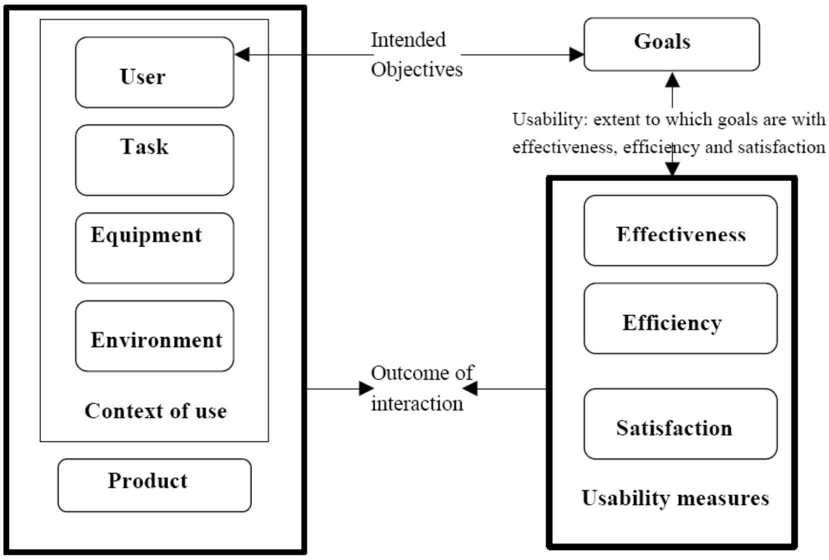


Figure 6.1 Usability framework (Source: ISO DIS 9241-11, see URL 6.1)

6.3. Evaluation methods

6.3.1. Usability testing methods

There are several evaluation methods described in literature that can be used in the usability testing of the prototype. Five methods including thinking aloud, focus group, questionnaires, heuristic evaluation and interviews are briefly explained as below:

- Think aloud method

As the name implies, think aloud is a method whereby the user is instructed to speak aloud their thoughts without interrupting him/her while he/she is working with a product to complete a task (Tsoene, 2004). Think aloud is a popular method for usability testing, it is supported and applied by many researchers in geovisualization (Ogao, 2002; Tsoene, 2004; van Elzakker, 2004; Blok, 2005). The think aloud method has some advantages, for example there is hardly any disturbance of the usability process. In addition, many data can be gathered without memory errors. However, the think aloud method also has disadvantages, such as it is very time consuming (van Elzakker, 1999).

- Focus group

A focus group session is defined as: “A carefully planned series of discussions designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment” (Krueger & Casey, 2000). Focus groups are group interviews or discussions (i.e., qualitative approach) (Morgan, 1998), the domain experts evaluate a product in the context of their domain and provide useful ideas for making further improvements (Blok, 2005). In a focus group session, a moderator guides the interview with a set of prepared questions, listens, keeps track of the conversation and makes sure everyone has a chance to share their experiences, memories, opinions and perceptions (Krueger & Casey, 2000). Basically, it requires six to eight participants who are in a similar domain and can openly discuss the issues addressed by the moderator (Morgan, 1998). The main advantage of this method is that it is a fast, easy, relatively inexpensive and efficient qualitative method. The main limitation is that the moderator has less control than in an individual interview. Therefore, it may lead to inefficient or biased results (Monmonier & Gluck, 1994; Blok, 2005). In a geovisualization context, this method has been applied by several researchers: Monmonier & Gluck (1994) applied focus group to evaluate dynamic maps; Tsoene (2004) used it to evaluate the usability of the visualization of metadata and Blok (2005) used this method to obtain options and reactions on an animation application to monitor of spatial phenomena.

- Questionnaires

Questionnaires are old tools with which you can study the user’s attitudes about a prototype (Tsoene, 2004). In a questionnaire method, the user is asked to write down answers to questions about a product. Two basic types of questions can be distinguished: closed and open-ended questions. For closed questions, a researcher provides a suitable list of responses (e.g. Yes/No) to produce mainly quantitative data, while for open-ended questions, the respondents are asked to answer "in their own words" to produce mainly qualitative data (see URL 6.2). Questionnaires are not very time consuming. In addition, questionnaires can be obtained from users who do not necessarily participate in a usability session: via an e-mail, on the internet or through a paper based questionnaire (see URL 6.3). Questionnaires via an email or on the internet can cover a wide region of the population, however, the response rate may be low and misunderstand questions cannot be explained.

- Heuristic evaluation

  In a heuristic evaluation, a small number of evaluators independently examine a product interface to judge how well it adheres to a list of heuristics (usability principals) (Nielsen, 1993). This method helps to obtain qualitative information about usability problems in the interface of a product. It is simple, relatively inexpensive method and it quickly provides results (see URL 6.3).

- Interviews

  The interview is a method that users are interviewed about their subjective reactions, opinions and expectations about a product. One interviewer gathers information about users by talking directly to them. Because of the one-to-one nature of the interview, mistakes and misunderstandings can be quickly identified and cleared up. Reports of interviews have to be carefully analysed because unstructured nature of the resulting data is extremely easily misinterpreted (see URL 6.4).

6.3.2. Evaluation methods selected for this research

For evaluating a product, more than one evaluation is recommended in the literature. By applying different evaluation methods, one can produces feedback in different ways and they all help to improve the product (Nielsen, 1993). The selection of evaluation methods depends on what evaluators want to know and in which stage of prototype development evaluators are. The think aloud method was considered for this research because it can obtain extensive information about a prototype. However, this method could not be applied due to the time limits. As mentioned above, the think aloud method is a very time consuming in its execution as well as in results analysis (van Elzakker, 1999).

In this research, the focus group and questionnaire method were employed and combined. The focus group method was selected because it is an effective and fast method for getting first impressions about the prototype design. Therefore, it is suitable for a first evaluation of a prototype. The questionnaire with closed questions was considered for the second session because it can be easily summarized and gives some quantitative results. The questionnaire method is also a very efficient method. The focus group method was applied in this research to minimize the usability problems in later usability testing. After the focus group, another session using the questionnaire method was organized, wherein questions were put forward to the participants about the usability of the animated representations in the prototype. The issues addressed in the questionnaire were, amongst others, the usability measures recommended by ISO 9241-11 as outlined in Section 6.2: *effectiveness*, *efficiency* and the degree of *satisfaction* (see 6.5.1 below).

6.4. Evaluation in a focus group session

6.4.1. Procedure and participants

The main goal (as indicated in 6.1) of the focus group session was to obtain feedback on a first design of the symbols. Another goal was to discuss the possible tasks that could be implemented in later evaluation session. Six domain experts agreed to participate in the focus group session. All participants of the group had an academic background and knowledge about spatial planning.

The session was held on 16 January 2008 in a closed conference room at Wageningen University (the Netherlands). A beamer and projection screen were available for the demonstration of the prototype. The session lasted about 1 hour and 10 minutes and was video-recorded to facilitate analysis.

The session started with an *opening speech* for 2 minutes to welcome the focus group participants and read a statement about voluntary participation, and the right to stop any moment. This was followed by an uninterrupted PowerPoint *presentation* including purposes of the focus group session, a brief introduction and a demonstration of the prototype for about 15 minutes. After the presentation, a few questions in a pre-arranged sequence were addressed to get the participants' reactions, opinions, ideas and suggestions:

1. For each of the planning objects separately, you have seen two animated approaches. What did you find most useful, and what seems useless, confusing, distracting, or frustrating? And which approach do you prefer?
2. Do you have further suggestions?
3. Could such a visual environment with animated representation of uncertainty and fuzziness, in theory, support experts to be better aware and informed about the uncertainties?
4. Do you have suggestions about one or more relevant tasks that I could give to participants of user evaluation ahead?
5. Have we missed anything?

The discussion focused on the potential usefulness and uselessness of each animated representation, the preferred animated approaches for the same planning object, and opinions about the usability score of such an animated representation of uncertainty and fuzziness that supports domain experts to became better aware and informed about the uncertainties. The session was executed as planned. All six experts contributed their opinions and provided wishes/suggestions to improve the prototype. In the 43 minutes of the focus group session, one of the participants, who could not stay for the whole session, had to leave.

6.4.2. Results

Results of the focus group session are summarized in Table 6.2.

- Some experts mentioned that it is impossible to precisely perceive the animated effects if the animated representations are only displayed once, although the prototype includes a REPLAY button. They suggested that all the animated representations should be repeated 3 times to enable the users to better perceive them.

- In order to facilitate usability testing, some animated instructions were designed and implemented to guide users through the usability tasks. Sometimes the animated instructions were displayed with the animated cartographic symbols at the same time in different representation windows. An expert pointed out that it diverts the user's attention and suggested to display it after the display of the animated cartographic symbols.
- One of the experts mentioned that the blurring in the animated representation of line planning objects cannot be clearly perceived.
- Another issue is the motion of the animated cartographic symbols of the landscape ecological zone (represented as an arrow in spatial planning maps). Initially the animated arrow symbol grew from the centre of the urban region to both sides of the urban fringe. One expert suggested that it should go from one urban side to another side, and then go back.
- A "stepping stones" method was suggested as a means to represent an animated cartographic representation of the landscape ecological zones.
- The first animated cartographic symbol of the area planning object should be add more zones.

Table 6.2 Summary of results of the focus group session

Wishes and suggestions
The animated representations -All animated representations should be repeated 3 times -Animated instructions should not be displayed with the animated cartographic symbols at the same time -Blurring used in point planning objects cannot be clearly to perceived -The motion of animated line symbols (arrows) should move between the two objects it connects - A "stepping stones" method was also suggested to represent the animated arrows symbols -The first animated cartographic symbol of the area planning object should be add more zones
Usability aspects
-Transparency is useful in most of the animated cartographic symbols -Selection of the animated representation methods should depend on the task and user requirements -It will support spatial planners to be better aware of the uncertainty and fuzziness

In the usability context, most experts mentioned that transparency is a useful graphic variable to design animated cartographic symbols because the degree of transparency does not obscure other planning objects in the spatial planning maps. During the discussion, the preference for alternative animated representation methods for the same planning objects was asked by the moderator. The experts could not make a choice because they believed that selection of the different methods should depend on the tasks and user requirements. Finally, the usability score of such an animated representation, meant to support experts to be better aware of and informed about the uncertainties, was addressed. All experts agreed that it will support spatial planners to be better aware of the uncertainty and fuzziness.

For possible tasks that could be implemented in later evaluation session, two experts suggested demonstrating the prototype to users, and then users tell what they observe from these animated representations. They also suggested using the think aloud method. In the later usability testing session, the think aloud method was not employed due to the time limits, the tasks suggested by the domain experts were applied in a questionnaire session.

6.4.3. Adaptations to the prototype

After the focus group session, all reported wishes/suggestions (see Table 6.2) provided by domain experts were added to / changed in the prototype. Two points need to be specifically addressed here:

- All the animated cartographic symbols are repeated 2 or 3 times depending on the length of the whole display time.
- The motion style of first animated cartographic symbol for the landscape ecological zone was not changed because the evaluator wants to use this symbol also in the later usability testing.

6.5. Usability testing

As mentioned before, usability evaluation is necessary because one of the objectives of this research is an effective visualization solution, and evaluating the usability of the prototype is addressed in another research objective. After the focus group method was applied, the questionnaire method was considered as a supplement wherein mainly closed questions and options to explain answers were put forward to the user about the effectiveness, efficiency and the degree of satisfaction of the animated representations in the prototype.

6.5.1. Description of goals and task for the test session

The main goal of usability testing was to assess if the aspects of uncertainty/fuzziness of the planning objects can be perceived. Another goal was to assess the usability of the proposed animated representations.

Starting from the test goals, the questions in this evaluation are:

1. Are the uncertain and fuzzy aspects in animated representations successfully identified by users?
2. What is the usability of the animated representations?
3. Do the animated representations reflect the reality?
4. Are such animated representations suitable for the exchange of fuzzy and uncertain spatial planning objects within the spatial planning process?

Test tasks were prepared based on these goals and questions (see Appendix 2). The scenario is that an expert involved in spatial planning needs to consult spatial plans in the preparation phase of a regional implementation plan. He/she wants to become aware of the uncertainties and fuzziness of the objects (e.g. be warned in case of a fuzzy boundary) to evaluate their impact on the execution of the spatial plans.

The scenario described above is accompanied by a number of tasks for user to perform. The tasks were formulated to assess the different animated representations of four types of planning objects (i.e. point, line, area planning objects and continuous phenomena). In task 1-4, users were required to tick the aspects of uncertainty/fuzziness that they can perceive for each of the animated representations, in addition they are asked to explain the reasons if they were unable to perceive any of the aspects for an animated representation. This was done to answer the evaluation question 1 mentioned above. The questionnaire was designed in such a way that for each task some quantitative data could be collected with respect to usability measures to answer question 2 above. Task 5 was designed to answer usability questions 3 and 4 above.

6.5.2. Materials

Two documents were prepared before the evaluation sessions were conducted. The first document, "*Familiarization with the interface*" (Appendix 1), was used to highlight elements of the prototype and to help users get familiar with the prototype interface. The second document, "*Tasks and questionnaire*" (Appendix 2), contains a description of evaluation tasks and questions as described in 6.5.1. It also contains questions related to the educational and professional background of the participants. Both documents were provided at the usability testing session.

6.5.3. Participants

The evaluation group consisted of nine participants: three ITC staff and three PHD students from the Department of Urban and Regional Planning and Geo-information Management and three ITC staff from the department of Geo-Information Processing. The selection of test users was related to their educational and professional background. The idea was to get users who have some knowledge of/experience in spatial planning. In addition, users from a geovisualization perspective were also considered valuable to assess visualization issues of the prototype.

At first, an invitation email was sent to the department of Urban and Regional Planning and Geo-Information Management 4 days before the test. In the email, the topic and time of the test were highlighted. As mentioned above, six participants replied that they were willing to attend. The three staff members of the Department of Geo-Information Processing were orally contacted. One day before the test, all participants were reminded, and more details were provided by e-mail (including the purpose of the test, planning and duration of each part, together with an abstract of the research). There were seven male and two female participants. The group was highly educated (see Appendix 3), three of the participants with a M.Sc. degree are currently PhD students in ITC.

6.5.4. Procedure

The evaluation session was conducted on 6th February 2008 in a closed student computer cluster in ITC. The session started at 13.45 and lasted for about 1 hour and 15 minutes. All the participants were invited to attend the test at same time in the same venue with enough computers to perform the tasks independently. The session began with a PowerPoint presentation which took approximately 10 minutes, the participants were given a brief introduction, mentioning the research problem and objectives, the conceptual framework, the purposes of the usability testing and a brief demonstration of the prototype to demonstrate the interface and some important base map layers. No detailed explanation and demonstration of the animated cartographic symbols of each planning object were given, because it could exert a subtle influence on the participant's perception in the test, while only the most direct thoughts, without any interference, can give independent usability scores for these animated representations. After the presentation, the two documents *Familiarization with the interface* (see Appendix1) and *Tasks and questionnaire* (see Appendix2) were provided to the participants. The time scheduled for familiarization with the prototype was 5-10 minutes. After that, participants executed the tasks and completed the questionnaires independently.

6.5.5. Results

To assess the results, the percentages of participants who were able to identify the intended aspects of uncertainty and fuzziness through the animated representations were calculated. Participants' view on the usability of the animated representations in terms of effectiveness, efficiency and satisfaction scores were determined. Possible scores ranged from 1 to 5 where 1 means *not*, 3 *moderate* and 5 *highly*.

6.5.5.1. Analysis of results: recognition of uncertainty and fuzziness

The percentage of participants who can correctly and easily identify the uncertainty/fuzziness through the animated representations is shown in Table 6.3. During the test session, one of the participants (P8) did not fill in the tasks results and some scale scores tables provided in the task documents; instead he provided separated comments on each of the animated representations which are summarized in Table 6.4. Therefore, the calculation of the percentage is made over 8 participants.

For both animated representations of point planning objects, 50% of the participants can correctly identify the uncertainty/fuzziness information. For the line planning objects, 75% of the participants can correctly identify the uncertainty /fuzziness information through the first animated approach, while 62.5% of the participants can perceive the intended aspects of uncertainty /fuzziness through the animated representation approaches 2 and 3. For area planning objects, the intended aspects of uncertainty/fuzziness can be respectively perceived by 50% and 62.5% of the participants through two animated representations. For the continuous planning objects, the difference between the two animated representations is larger: 75% of the participants can correctly identify the uncertainty/fuzziness information in the animated approach 1, whereas only 37.5% of the participants can identify the intended uncertainty and fuzziness aspects from the animated approach 2. The reasons why uncertainty/fuzziness could not be identified are summarized in Table 6.5.

Table 6.3 Number of the participants who can identify the uncertainty and fuzziness in each of the animated representations expressed as percentage.

Planning objects types	Animated approaches	Number of answers	Test participants									Percentage of correct identification
			P1	P2	P3	P4	P5	P6	P7	P8 *	P9	
Point	1	6	●	●		○		○	●		●	50%
	2	7	●	●		○	●	○	○		●	50%
Line	1	7	●	●	○	●	●		●		●	75%
	2	6	○		●	●	●		●		●	62.5%
	3	7	○	●	●	●	●		○		●	62.5%
Area	1	7	○	○	○	●	●		●		●	50%
	2	7	○	●	○	●		●	●		●	62.5%
Continuous phenomena	1	7	●	●		○	●	●	●		●	75%
	2	3				●		●	●			37.5%

●=correct identification ○=incorrect identification

(*P8 provided the separate comments of the animated representations instead of filling in the tasks results and some scale score table in the questionnaire, his comments is summarized in Table 6.4. Therefore the calculation of the percentage did not include P8)

Table 6.4 The comments provided by P8

Planning objects types	Test participant P8
Point planning objects	Animated approach 1 is better
Line planning objects	Animated approach 3 is good
Area planning objects	None of the animated approaches shows the whole uncertainty information, but the morphing is a good way of representation
Continuous planning objects	Animated approach 2 is more proper because it shows clearly the two different sizes of the circles

The results presented above reveal that most of the participants can perceive the uncertainty/fuzziness information from all the animated representations with an exception of the second animated approach of the continuous phenomena planning objects. However, the percentage of correctness is not very high. According to the analysis of the wrong recognitions, almost all of the wrong recognitions are because the participants incorrectly identified the orientation uncertainty in the animated cartographic symbols. Based on the reasons on Table 6.5, it can be concluded that some participants cannot identify the uncertainty/fuzziness due to the clearly defined and represented boundary/size in the animated representations. Therefore, the transparency or colour saturation change in boundary/size does not clearly provide the uncertainty/fuzziness information for them.

Table 6.5 Reasons why uncertainty/fuzziness could not be identified

Planning objects	Animated approaches number	Test Participants	Reasons why uncertainty/fuzziness could not be identified
Point	1	P3	Have no idea
		P5	Clear boundary/size, only transparency change does not clearly indicate fuzziness
	2	P3	Have no idea
Line	1,3	P6	The definition of the landscape ecological zone is not exactly spatially defined, all representation are equally clear and animation does not really aid
	2	P2	No uncertainties since it shows clearly defined line and boundary
		P6	The definition of the landscape ecological zone is not exactly spatially defined, all representation are equally clear and animation does not really aid
Area	1	P6	Did not mention
	2	P5	Looks just animated growth, area looks defined
Continuous Phenomena	1	P3	Did not mention
	2	P1	Did not mention
		P2	All is set rather "hard", boundaries are fixed, so no real uncertainty
		P3	Can only distinguish 3 levels zones
		P5	Transparency does not clearly indicate fuzziness
		P9	I would feel these are 3 fixed (discrete) levels of noise

6.5.5.2. Analysis of usability scores

Usability scores are collected to evaluate the participant's view on effectiveness, efficiency and satisfaction. Questions 2, 4, 6 and 8 in the tasks and questionnaire document (see Appendix 2) focused on measuring the usability measures for each animated representation of the planning objects. For the analysis of the results, each scale score provided by the participants is shown in Appendix 4. The score range varied from 1 (not), 3 (moderate) to 5 (highly). The average scores were also calculated to indicate the overall usability results of individual animated approaches in each type of the planning objects (see Appendix 5).

For point planning objects, the effectiveness, efficiency and satisfaction of the second approach which are 3.83, 3.83 and 3.5 respectively are higher than the first approach, although the differences are very small. Both of them have moderate scores (see Figure 6.2).

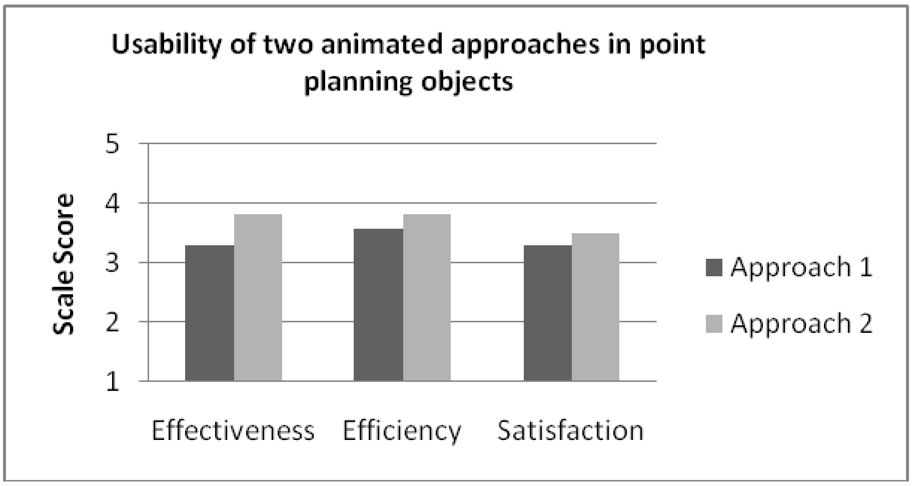


Figure 6.2 Usability comparison of two animated approaches in point planning objects

The overall effectiveness of three animated methods represented on line planning objects shows that the first approach was moderately effective (3.71) followed by the second approach (3.14). The third approach is least with score 3 but this is still moderately effective. To measure the efficiency of them, the first animated approach performed well with score 3.86 followed by the second animated approach with score 3.14. The third animated approach took the least score 2.89. Towards the degree of participants' satisfaction, the analysis results show that the participants were much satisfied with the first animated approach with score 4 followed by the third animated approach with score 3.2, the least one is the second animated approach with score 3.14 (see Figure 6.3).

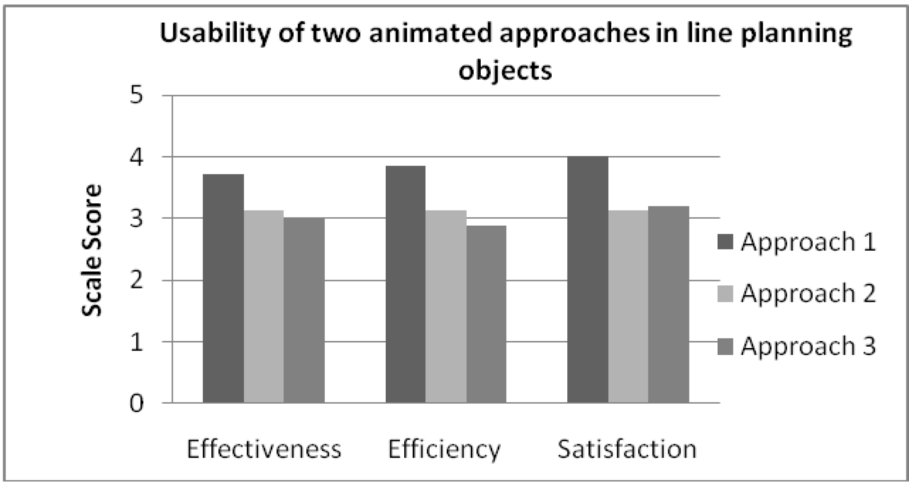


Figure 6.3 Usability comparison of three animated approaches in line planning objects

For area planning objects, the overall response about effectiveness, efficiency and satisfaction of the first animated approach are 4.13, 4 and 3.88, which are highly effective, highly efficient and moderately satisfactory. The second approach gained the scores moderately effective (3.33), efficient (3.33) and satisfied (3.22) (see Figure 6.4).

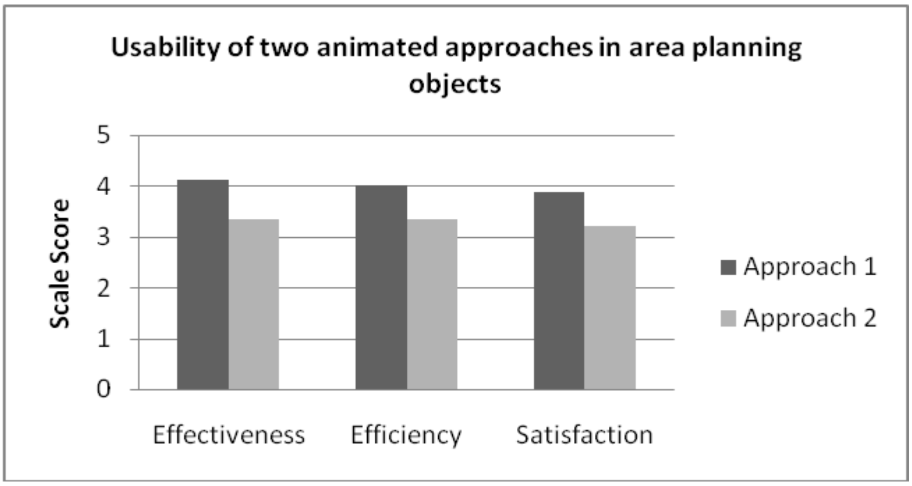


Figure 6.4 Usability comparison of two animated approaches in area planning objects

For continuous phenomena planning objects, the first approach gained higher score of effectiveness, efficiency and satisfaction than the second approach as shown in Figure 6.5.

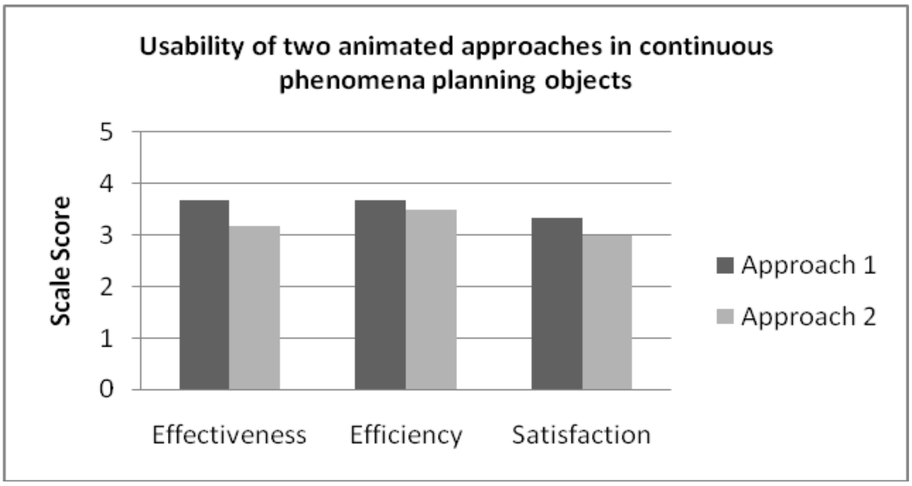


Figure 6.5 Usability comparison of two animated approaches in continuous phenomena planning objects

Table 6.6 Overall rating of the extent to which the animated representations reflect reality

Extent to which the animated representations reflect reality	Number of participants
5 (realistic)	0
4	2
3 (moderate)	5
2	2
1 (abstract)	0

Question 9 in the usability task and questionnaire document aimed to collect the opinion of participants about the degree of reality in the animated representations. A 5 scale score was also provided here: from 1 (abstract), 3(moderate) to 5 (realistic). The results collected are displayed in Table 6.6. Most of the participants (5 in total) agreed that the animated representations moderately reflect reality. The participants were also asked to give a general suitability score of these animated representations for the exchange of spatial plans in the Netherlands. The answers given are described in Table 6.7.

Table 6.7 Suitability score of the animated representations for the exchange of spatial plans in the Netherlands

Suitability of the animated representations for the exchange of spatial plans	Number of participants
5 (high)	1
4	1
3 (moderate)	5
2	1
1 (low)	1

Question 11 in the usability tasks and questionnaire asked to estimate the chances that the animated representations presented would be implemented in a real spatial planning process in the Netherlands from a conceptual, technical, legal and policy point of view. The scores are such that 1 refers to simple, 3 refers to moderate and 5 refers to problematic. The average results from participants were calculated in Table 6.8. Finally, some additional comments were collected from some participants and they are presented in Table 6.9.

Table 6.8 Estimated chances for implementation of the animated representations in a real spatial planning process in the Netherlands from a conceptual, technical, legal and policy point of view.

Chances for implementation(1 simple, 3 moderate, 5 problematic)	Scores
Conceptual	2.19
Technically	1.94
Legally	3.43
Policy	3

Table 6.9 Additional comments from participants

Participants	Additional comments
P2	For greenhouse growth, show more gradual growth in time to highlight conflicts with roles and regulations.
P4	Animation is helpful, but the context of objective is more important when it is presented.
P5	Simple transparency is not clear to indicate fuzziness
P7	Some animations are too fast. Personally, blurring is the best.
P8	See Table 6.4

6.6. Discussion

The results of correct recognitions reveal the percentage of correctness is not very high. According to the analysis of the wrong identifications, almost all the wrong recognitions are because the participants incorrectly identified orientation uncertainty in the animated cartographic symbols. In fact, none of the planning objects tried to represent orientation uncertainty because the examples did not have the orientation uncertainty aspect. It reveals that the animated representations give participants an impression of uncertain orientation. This may be because the size fluctuation (change) gives them this impression. In reality, the location, boundary, orientation, size and shape aspects in planning objects are all related, therefore, the confusion in identification of the aspects is hard to avoid. In addition, based on the reasons why uncertainty/fuzziness could not be identified, some participants thought that the clearly defined and represented boundary/size in the animated representations could not represent the uncertainty/fuzziness. It can be concluded that the transparency or colour saturation change in boundary/size does not clearly provide the uncertainty/fuzziness information for them. A way that tries to avoid these two problems above is to provide detailed plan regulations (or metadata) for the animated cartographic symbols.

The uncertainty/fuzziness information of the second approach for continuous planning objects could be perceived by 3 participants only. However, 6 participants provided its usability scores and the results show that its usability scores are unexpected high (see Appendix 5). Therefore, the usability result for the second approach of continuous planning objects is may not be reliable. Other usability scores relate well to the results of correct recognition. In addition, the difference of usability scores of different approaches for the same planning objects is very small. It reveals that the preference of the different approaches is not obvious.

Several participants did not provide reasons for the unanswered usability testing questions. Through in discussion with them after the session, they mentioned that the reason was that they sometimes did not understand the tasks or questions or symbols well. It probably because no detailed explanation and demonstration of the animated cartographic symbols of each planning object was given in the presentation, since the evaluator did not want to exert a subtle influence on the participant's perception in the test. The participants who did not provide reasons were not very familiar with Dutch spatial planning; it was hard for them to provide usability scores. The average usability scores do not include their results; it is fair in the context of statistics. However, it reveals the importance of the plan regulations (or metadata) as mentioned by P4 in Table 6.9. In addition, one participant mentioned that he got confused about the point planning objects. He expected, for example, that the aquatic recreation was a point object and did not understand why the symbols showed it as areas in the animated representation window. An explanation to avoid this confusion is that two sources of uncertainty and fuzziness include planning objects that appear as point, line or area symbols on the map, and continuous phenomena that are currently represented by crisp boundaries. Therefore, point, line or area refers to the symbols on the map, not necessarily to the planning objects themselves.

Comparing the results collected from the focus group session and the questionnaire session, one expert in the focus group suggested that the motion of the animated representations of landscape ecological zones should be designed as going from one side of the urban region to another side and then going back. However, in the questionnaire session, this method (the animated approach 3 of the line planning objects) did not get higher scores in effectiveness, efficiency and satisfaction than the animated approach 1 of the line planning objects (see Figure 6.3). The two evaluation session are different in the users group and adopted method, it cannot be concluded what is right. Therefore, it reveals that the usability results sometimes are different in different user groups. The participants in the two sessions had different academic background and core activities, so they may have had different purposes and views when they assessed the representations, and it may cause the different opinions. Also, the participants of the focus group were more familiar with the data and with Dutch spatial planning.

The objective of this research was to help spatial planners to be better aware of the uncertainty and fuzziness, however, most of the participants both in the focus group session and the tasks and questionnaire session are researchers in spatial planning or geovisualizaion, none of them are spatial planners. It influences the usability results to a certain extent. In addition, one condition in the tasks and questionnaire session limited the results. According to the literature (such as Nielsen, 1993), the suggestion about number of participants for a usability testing is 3-5. Although 9 participants in this research is larger than it, it is not enough to really quantify the results and make them statistically valid with only 9 test participants. Therefore, more participants are suggested for the further research. Furthermore, if realistic planning tasks with detailed plan regulations could be employed to test the usability of the uncertainty and fuzziness representations, these tasks may help the participants to understand the animated representations, and therefore the participants can better assess the animated representations.

6.7. Summary

Based on the selected evaluation method i.e. focus group and questionnaire, results of usability of the animated representations of planning objects were gathered and analysed in this chapter. First, the focus group method was applied. The results show that all the domain experts who participated agree that such an animated representation will support spatial planners to be better aware of the uncertainty and fuzziness. The wishes and suggestions from the focus group session were adapted to the prototype to minimize the usability problem for later usability testing session. After the adaptation, the questionnaire survey was conducted to test the usability of the adapted prototype. The results show that all these suggested animated cartographic symbols gain moderate or more than moderate effectiveness, efficiency and satisfaction.

7. Conclusions and recommendations

The focus of this research was on the use of animated representations to display uncertainty and fuzziness in spatial planning maps. The research has limited itself to the animated representation by means of the combination of graphic and dynamic visualization variables. One of the main objectives was to develop methods to effectively visualize uncertainty and fuzziness in animated representations, since little work has been done on animated ways. The other objective was to select or develop a method by which the usability of uncertainty and fuzziness display in spatial planning maps can be evaluated. Investigation of the animated cartographic symbols by the use of graphic and dynamic visualization variables and evaluation of their use in a prototype by different kind of domain experts in spatial planning and visualization has been performed to meet the research objectives. This chapter covers the conclusions about this research and the recommendations for further research.

7.1. Conclusions

The main conclusions are summarized here by answering the research questions.

1. *Which planning objects are uncertain and fuzzy in spatial planning maps?*

Chapter 2 looked at issues related to uncertainty and fuzziness in spatial planning maps. Two sources of uncertainty and fuzziness were identified: incompletely defined planning objects and discretely defined continuous phenomena (fuzzy planning objects). Two sources of uncertainty and fuzziness include planning objects that appear as point, line or area symbols on the map, and continuous phenomena that are currently represented by crisp boundaries. Therefore, these two sources result in planning objects that are uncertain and fuzzy in spatial planning maps.

2. *What characteristics of the uncertain and fuzzy planning objects play a role in the plan preparation phase of spatial planning?*

In Chapter 2, five aspects of uncertainty and fuzziness of planning objects are distinguished in the geometrical domain: location, orientation, boundary, size and shape. Currently, the uncertain and fuzzy planning objects are represented as crisp and static cartographic symbols and the aspects of uncertainty and fuzziness are not precisely represented in spatial planning maps. Therefore, spatial planners, who are in the plan preparation phase of spatial planning, may not be aware of the uncertainty or cannot easily detect it in a digital environment. Answering questions 1 and 2 is an essential step on the way towards the development of a conceptual framework and the creation of animated representations.

3. *How can these planning objects be represented in an (interactive) animated way by combinations of graphic and dynamic visualization variables?*

An investigation into the way in which graphic and dynamic visualization variables can be used to represent uncertain and fuzzy objects was undertaken. After investigating the characteristics of graphic and dynamic visualization variables, the issues of visually representing uncertainty and fuzziness are addressed in Chapter 3. Subsequently, a conceptual framework for animated representations of uncertainty and fuzziness in spatial planning maps is proposed in Chapter 4. The combinations of graphic and dynamic visualization variables can create animated cartographic symbols to represent the uncertainty and fuzziness aspects of a planning object. Planning objects that may have some or all of the uncertain and fuzzy aspects can be represented using a combination of animated cartographic symbols. The animated representations are displayed in an interactive way, e.g. when users click on an uncertain or fuzzy planning object in the map, the animated representation is displayed at a larger scale.

4. *How can the annoyance of users by some animated effects e.g. moving or blinking objects be eliminated?*

Many animated cartographic symbols displayed on a small scale map may make users become annoyed. Therefore, a way to avoid this problem was considered, by displaying the animated cartographic symbols at a larger scale. In the prototype, two display windows were designed: a map window and an animated representation window. The map window is for the representation of the spatial planning map. When users click on an uncertain/fuzzy planning object in the map window, the animated representation is displayed at a larger scale in the animated representation window. The animated representation window only displays the planning object(s) of a small region rather than a whole regional planning map. Therefore, annoyance of excessive animated cartographic symbols can be reduced, or even be avoided.

5. *How to select or develop a method for testing and evaluating whether the proposed application works?*

The main aim of the evaluation in this research is to test the usability of the proposed animated representations. The definition adopted for this research is the one proposed by the ISO. In this context, the usability of the animated representations is seen as the extent to which they can be used by domain experts and users in the spatial planning processes to perceive uncertainty/fuzziness effectively, efficiently and satisfactory. Therefore, the main goals of usability testing were to assess if the aspects of uncertainty/fuzziness of the planning objects can be perceived, and to assess the usability of the proposed animated representations. After investigating the main usability testing methods in literature, the focus group and questionnaire method were selected based on the available time and the evaluation goals. The focus group method was selected and applied to obtain a first feedback and to minimize the usability problems in the later usability test session. After the focus group method was applied, some adaptations were made in the prototype, followed by a task and questionnaire session wherein mainly closed questions were put forward to the users to get some quantitative results on the effectiveness, efficiency and satisfaction.

6. *Which combinations of variables can be recommended to aid spatial planners in making better decisions, based on user tests?*

A start was made with the establishment of a conceptual framework, some animated cartographic symbols using graphic and dynamic visualization variables to represent each of the uncertainty and fuzziness aspects were suggested. Some applications of these animated cartographic symbols were made in a prototype, and evaluated. After the focus group session and the task and questionnaire session, the results show that all the suggested animated cartographic symbols that were tested gained moderate or higher than moderate effectiveness, efficiency and satisfaction. It means that the combination of the suggested variables can be recommended to aid spatial planners in making better decisions.

7.2. Recommendations for further research

Recommendations for further research are:

- To investigate further extensions of the conceptual framework. In the prototype, the animated behaviour of the symbols was influenced by the local context in which it appeared, so a generic application is not yet possible. A legend of animated cartographic symbols should be established.
- The animated cartographic symbols are designed and implemented in 2D space. One recommendation is to extend the animated cartographic symbols to 3D space, e.g. representing a noise area as a sphere instead of one or more circles.
- The selection of participants used for the task and questionnaire session was made by considering people who have some knowledge of /experience in spatial planning or/and geovisualization. All the participants were invited to attend the test at the same time in the same venue. More tasks and different questions should be taken into account to establish testing sessions in different user group, e.g. using spatial planners who are doing a realistic planning task to test the usability of the uncertainty and fuzziness display.
- The prototype developed in this research is used for demonstration and testing of the animated representations. This prototype had certain limitations e.g. the zoom in of the regional planning map is simulated in the animated representation window. Hence it can be explored to develop such a visualization tool using platforms like java, visual c++ etc.

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Appendices

Appendix 1: Usability testing exercise

Familiarization with the interface (10 minutes)

After opening, the default display looks like this *(figure 1)*:

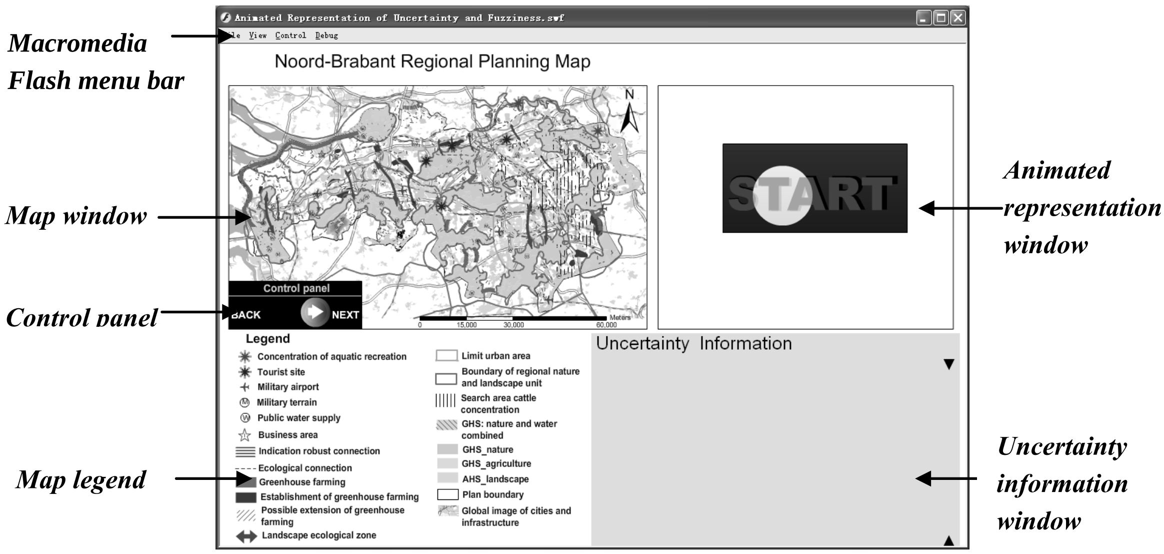

Figure 1. The default display of the prototype window

Have a look at the following elements of the prototype

- The map window

Here, the regional planning map of the province Noord-Brabant is displayed.

- The control panel

The control panel includes BACK and NEXT buttons, set according to the sequence of evaluation tasks; you can interact with these two buttons.

- The map legend

The map legend is clickable, the map layers can be switched on and off by clicking on the categories in the map legend. (Please remember to switch on again the layers that you switched off before you with the tasks).

- The animated representation window (see figure 2)

After clicking START and a planning object in the map window, animated representations of fuzzy and uncertain planning objects are here displayed at a larger scale than in the map window. The animated representations title identifies the displayed planning objects. The REPLAY button can be used to replay the animated representations.

- The uncertainty information window

Detailed uncertainty or fuzziness information is displayed in this area. You can scroll up and down by clicking on the arrow buttons if not all information fits in the display area of this window.

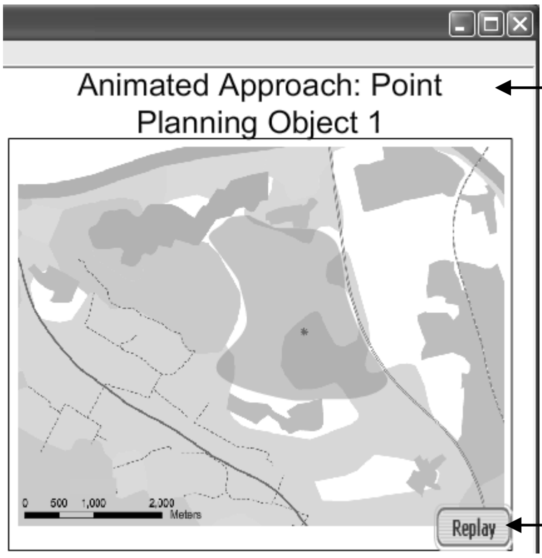

Figure 2. The animated representation window

Appendix 2: Usability testing tasks and questionnaire

Tasks and questionnaire (50 minutes)

Scenario:

An expert involved in spatial planning wants to gain insights in the regional plans of a particular area. Plans in which the *strategic* vision of the province has been laid down are available. The expert needs to consult these plans in the preparation phase of a regional *implementation* plan. The strategic vision contains solid (crisp) boundaries of the planning objects. The expert wants to become aware of the uncertainties and fuzziness of the objects (e.g. warn in case of fuzzy boundary) to evaluate their impact on execution of the spatial plans.

The expert will use the Noord-Brabant regional plan of 2002; it contains the provincial strategic vision for the period 2002-2012. The main purpose of this regional plan is to pursue a more careful zoning of space use. In the regional plan map, 20 map layers are available (see figure 3).

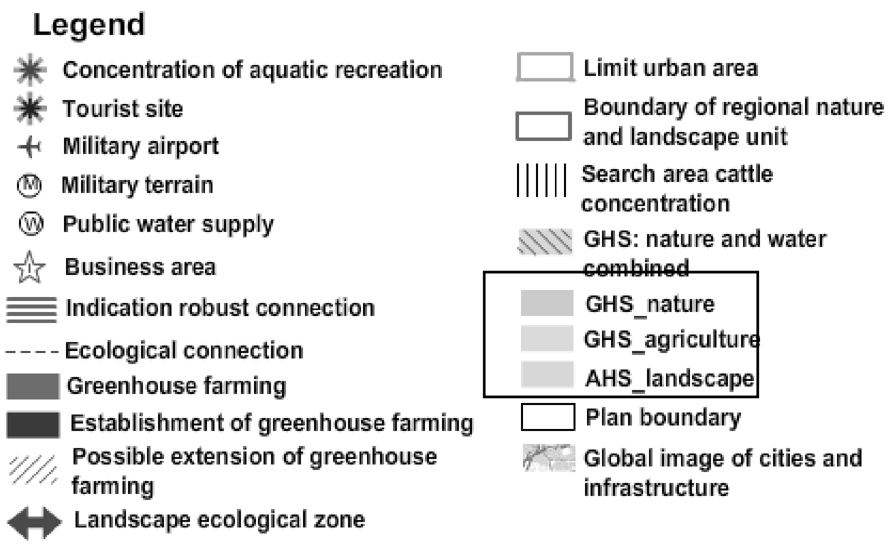

Figure 3. The legend of the regional plan

Three map layers are emphasized in figure 3; they all impose some limitations on implementation plans:

- GHS_nature and GHS_agriculture (GHS stands for Groene HoofdStructuur, or Main Green Structure). Their boundaries and surface are strict; they should not be occupied by other planning objects.
- AHS_landscape (AHS stands for Agrarische HoofdStructuur, or Main Agricultural Structure). AHS landscape areas sometimes might be used for other objects. In such cases, nature and landscape values should be preserved, or else compensated.

Important definitions of usability measures:

Effectiveness: The accuracy and completeness with which users achieve a specific goal.
Efficiency: The resources (e.g. time, effort) spend in relation to the accuracy and completeness with which users achieve a goal.
Satisfaction: The comfort and acceptability of use.

Now imagine that *you* are the expert. Use your domain knowledge to assess:

- If the aspects of uncertainty / fuzziness of the planning objects can be perceived;
- What the usability of the proposed animated representations is.

Please deal with the tasks and questions in the sequence indicated below.

Task 1

Click START, then follow the animated instructions to display point planning object 1 (aquatic recreation) and its uncertainty information, appearing in a separate window. Then click NEXT to see an alternative representation (point planning object 2).
(You can click the BACK button in the control panel and the REPLAY button in the animated representation window, if you want).

Please try to answer the following questions.

1. In the table below, five aspects of uncertainty / fuzziness are mentioned. Please tick (for each planning object) all the aspects that you perceive as uncertain / fuzzy from the animated representations. If you are unable to perceive any of the aspects for an object, please explain.

Animated representations	Aspects of uncertainty or fuzziness				
	Location	Boundary	Orientation	Size	Shape
Point planning object 1					
Point planning object 2					

I cannot identify any aspects of uncertainty / fuzziness in:

Object no.	Explanation

2. Please rank the two animated representations that you just observed in terms of effectiveness, efficiency and satisfaction *(if necessary, refer back to the definitions of these measures above)*. Ranking can be done on a scale from 1 (not) to 5 (highly) effective, efficient or satisfactory.

Effectiveness:

Point planning object 1	1	2	3	4	5
Point planning object 2	1	2	3	4	5

Efficiency:

Point planning object 1	1	2	3	4	5
Point planning object 2	1	2	3	4	5

Satisfaction:

Point planning object 1	1	2	3	4	5
Point planning object 2	1	2	3	4	5

Task 2

Please click NEXT and follow the animated instructions to display the alternative visualizations of the line planning object (landscape ecological zone) and its uncertainty information, and try to answer the following questions.

3. Please tick in the table below (for each planning object) all the aspects that you perceive as uncertain / fuzzy from the animated representations. If you are unable to perceive any of the aspects for an object, please explain.

Animated representations	Aspects of uncertainty or fuzziness				
	Location	Boundary	Orientation	Size	Shape
Line planning object 1					
Line planning object 2					
Line planning object 3					

I cannot identify any aspects of uncertainty / fuzziness in:

Object no.	Explanation

4. Please rank the three animated representations that you just observed in terms of effectiveness, efficiency and satisfaction. The scale of the rankings is the same as in question 2.

Effectiveness:

Line planning object 1	1	2	3	4	5
Line planning object 2	1	2	3	4	5
Line planning object 3	1	2	3	4	5

Efficiency:

Line planning object 1	1	2	3	4	5
Line planning object 2	1	2	3	4	5
Line planning object 3	1	2	3	4	5

Satisfaction:

Line planning object 1	1	2	3	4	5
Line planning object 2	1	2	3	4	5
Line planning object 3	1	2	3	4	5

Task 3

Please click NEXT and follow procedures outlined in the previous tasks to display alternative visualizations of the area planning object (greenhouse farming). Then try to answer the following questions.

5. Please tick in the table below (for each planning object) all the aspects that you perceive as uncertain / fuzzy from the animated representations. If you are unable to perceive any of the aspects for an object, please explain.

	Aspects of uncertainty or fuzziness				
Animated representations	Location	Boundary	Orientation	Size	Shape
Area planning object 1					
Area planning object 2					

I cannot identify any aspects of uncertainty / fuzziness in:

Object no.	Explanation

6. Please rank the two animated representations that you just observed in terms of effectiveness, efficiency and satisfaction. The scale of the rankings is the same as in question 2.

Effectiveness:

Area planning object 1	1	2	3	4	5
Area planning object 2	1	2	3	4	5

Efficiency:

Area planning object 1	1	2	3	4	5
Area planning object 2	1	2	3	4	5

Satisfaction:

Area planning object 1	1	2	3	4	5
Area planning object 2	1	2	3	4	5

Task 4

Please click NEXT and follow procedures outlined in the previous tasks to display alternative visualizations of the continuous planning object (noise zone and boundaries). Then try to answer the following questions.

7. Please tick in the table below (for each planning object) all the aspects that you perceive as uncertain / fuzzy from the animated representations. If you are unable to perceive any of the aspects for an object, please explain.

Animated representations	Aspects of uncertainty or fuzziness				
	Location	Boundary	Orientation	Size	Shape
Continuous planning object 1					
Continuous planning object 2					

I cannot identify any aspects of uncertainty / fuzziness in:

Object no.	Explanation

8. Please rank the two animated representations that you just observed in terms of effectiveness, efficiency and satisfaction. The scale of the rankings is the same as in question 2.

Effectiveness:

continuous planning object 1	1	2	3	4	5
continuous planning object 2	1	2	3	4	5

Efficiency:

continuous planning object 1	1	2	3	4	5
continuous planning object 2	1	2	3	4	5

Satisfaction:

continuous planning object 1	1	2	3	4	5
continuous planning object 2	1	2	3	4	5

Task 5

Please click NEXT and follow the instructions to display the combination of animated planning objects, together with uncertainty information. Then try to answer the following questions.

9. How do you rate the animated representations on the following scale?

1	2	3	4	5

abstract moderate realistic

10. How do you rate the suitability of the animated representations for the exchange of fuzzy and uncertain aspects of planning objects in the spatial planning process?

1	2	3	4	5

low moderate high

11. This is an innovative way to deal with uncertainty and fuzziness. How do you assess the chances for implementation of the animated representations presented in a real spatial planning process in the Netherlands?

Conceptual	1	2	3	4	5
Technically	1	2	3	4	5
Legally	1	2	3	4	5
Policy	1	2	3	4	5

Simple Moderate Problematic

12. Please add here any additional comments (e.g. about individual animated representations in the prototype, suggestions etc.).

………
………
………
………

<u>Professional information and experience</u>

1. Your educational background is:

O higher vocational training, namely: ………………………………...................................... ……
O university degree in: ……………………………………………………................... …………

O other: ………………………………………………………………..

2. What is your current status?

O student in (course): ……………………………………………………….......
O employed
O other: ………………………………………………………………………………………..........

3. If you are employed, what is your current function?

………

………

4. And what is (are) your core activity (activities) in that function?

O management
O planning
O education
O research
O other: ………………………………………………………………………………………............

5. Do you have experience in spatial planning?

O < 1 year
O 1-3 years
O > 3 years
O no experience

6. Have you ever encountered uncertainty or fuzziness in spatial plans?

O yes, regularly
O yes, occasionally
O no

THANK YOU VERY MUCH FOR YOUR PARTICIPATION!

If you have more comments, please let me know when I can come to collect or discuss them. Here is my e-mail; Zhang16560@itc.nl

Appendix 3: Participants details

Participants	Educational background	Main discipline	Current status	Current function	Core activities	Experience in spatial planning	Encountered uncertainty/fuzziness in spatial plans
P1	Higher vocational training	Cartography	Employed	Teacher	Education	No experience	Yes, occasionally
P2	Higher vocational training	Cartography	Employed	Lecturer	Education	No experience	No
P3	Higher vocational training	Cartography	Employed	Lecturer Map design	Education	Yes	Yes, regularly
P4	M.Sc.	Urban Planning	Employed/ Ph.D student in ITC	Urban planner in Chin	Planning Education	>3 years	Yes, regularly
P5	M.Sc.	Human Geography	Employed	Lecturer	Education	>3 years	Yes, regularly
P6	Ph.D.	Human geography and planning	Employed	Lecturer	Education	1-3 year in teaching context	Yes, regularly
P7	Ph.D.	Geography	Employed	Associate Professor	Education Research	>3 years	Yes, regularly
P8	M.Sc.	Urban Planning	Employed/ Ph.D student in ITC	Professional planner (urban and regional)	Management Planning Education Research	10 years	Yes, regularly
P9	M.Sc.	Civil engineer	Employed/ Ph.D student in ITC		Management Planning	>3 years	Yes, regularly

Appendix 4: Individual results on the usability of the animated approaches

Table 1 Individual results on the usability of the animated approaches in each type of the planning objects from participants

Planning objects types	Animated approaches	Usability measures	Test participants								
			P1	P2	P3*	P4	P5	P6	P7	P8**	P9
Point planning objects	Approach 1	Effectiveness	3	2		3	3		4	3	5
		Efficiency	3	3		3	3		5	3	5
		Satisfaction	3	3		3	2		5	2	5
	Approach 2	Effectiveness	2	4		5	4		5		3
		Efficiency	2	3		5	4		5		4
		Satisfaction	2	4		5	3		4		3
Line planning objects	Approach 1	Effectiveness	4	4		3	3	5	3		4
		Efficiency	4	4		3	3	4	4		5
		Satisfaction	4	5		3	2	4	5		5
	Approach 2	Effectiveness	4	1		5	3	5	2		2
		Efficiency	3	2		5	4	4	3		1
		Satisfaction	4	2		5	3	4	3		1
	Approach 3	Effectiveness	1	3	1	3	4	5	5	3	2
		Efficiency	2	3	1	3	4	5	4	3	1
		Satisfaction	2	3	1	3	4	5	5	3	3
Area planning objects	Approach 1	Effectiveness	4	5	5	5	3	5	2		4
		Efficiency	3	4	5	5	3	5	3		4
		Satisfaction	4	4	5	5	2	5	2		4
	Approach 2	Effectiveness	4	2	4	4	2	3	4	2	5
		Efficiency	4	2	4	4	2	3	4	2	5
		Satisfaction	4	3	4	4	1	3	4	2	5
Continuous planning objects	Approach 1	Effectiveness	4	5		2	4	3	4		
		Efficiency	4	4		2	4	3	5		
		Satisfaction	4	4		2	5	2	5		
	Approach 2	Effectiveness	1	3		5	2	4	4		
		Efficiency	1	3		5	2	5	5		
		Satisfaction	1	4		5	2	3	3		

(*P3 commented that, honestly, he did not have an idea of the suitability of these representations. **As mentioned above, P8 did not fill in most of the tables, instead, he provided separate comments).

Appendix 5: Averaged numerical results of the usability

Table 1 Averaged numerical results of the usability of individual animated approaches in each type of planning objects

Planning objects types	Animated approaches number	Number of answers	Effectiveness	Efficiency	Satisfaction	Overall usability score
Point planning objects	1	7	3.29	3.57	3.29	3.83
	2	6	3.83	3.83	3.5	3.72
Line planning objects	1	7	3.71	3.86	4	3.87
	2	7	3.14	3.14	3.14	3.14
	3	9	3	2.89	3.2	3.03
Area planning objects	1	8	4.13	4	3.88	4.00
	2	9	3.33	3.33	3.22	3.29
Continuous planning objects	1	6	3.67	3.67	3.33	3.56
	2	6	3.17	3.5	3	3.22

Appendix 6: Compact Disk containing the prototye of Animated Representation of Uncertainty and Fuzziness

This CD contains the prototype of Animated Representation of Uncertainty and Fuzziness in spatial planning maps developed during this research.